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FINAL
LAND APPLICATION OF WASTEWATER
PHASE I
PRELIMINARY ASSESSMENT
MISSOULA, MONTANA

PLEASE RETURN

JANUARY, 1992

THOMAS, DEAN & HOSKINS INC.
ENGINEERING CONSULTANTS
GREAT FALLS — BOZEMAN — KALISPELL, MONTANA
SPOKANE, WASHINGTON

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COST ESTIMATES

MISSOULA LAND APPLICATION STUDY - PRELIMINARY REPORT 1
Prepared by: Spratt & Associates, Consulting Hydrogeologists

MISSOULA LAND APPLICATION STUDY - PHASE I: PRELIMINARY EVALUATION OF IRRIGATION AND CROP ALTERNATIVES
Prepared by: Dr. William Inskeep, Soil Chemist

MISSOULA LAND APPLICATION STUDY - PHASE 1 TASK C
RAPID INFILTRATION ALTERNATIVE
Prepared by: Spratt & Associates, Consulting Hydrogeologists

SECTION I

INTRODUCTION

PURPOSE

Eutrophication of the Clark Fork River is an item of environmental concern that is most apparent during the warm summer months. Phosphorous has been identified as the most critical nutrient causing degradation of the stream. The river receives treated wastewater containing phosphorous compounds from Missoula and numerous other communities. Although Missoula's discharge permit currently does not impose a phosphorous limit, the City wants to cooperate where possible in maintaining or improving the water quality of the river. The purpose of this study is to evaluate the potential for land application of the treated effluent which would help reduce the overall phosphorous load on the river.

SCOPE

Three types of land application systems considered in this report are: (1) wetlands; (2) irrigation; and, (3) rapid infiltration. Wetland systems were only reviewed for general application requirements and required area size. Cost estimates for a wetland system were not included as part of this study. Land application was only considered for the summer months since this is the most critical period for the river. Storage of wastewater effluent during the non-irrigation season was not considered. All three types of land application were initially evaluated for a future average day flow of 9 million gallons per day (MGD). The current average wastewater flow is about 6.4 MGD. At the special request of the City of Missoula and the Clark Fork Coalition, the scope of work was expanded to include a further evaluation of the irrigation option for wastewater flows of 3 MGD and 6MGD. Consideration of potential legal issues relative to downstream water rights on the wastewater treatment plant effluent that will no longer be discharged to the river were not included in the scope of this study.

STUDY AREA

Evaluation of land application alternatives was limited to sites within the study area boundary as shown on Figure 1. This boundary encompasses land within a reasonable distance of the treatment plant that is generally practical to utilize.

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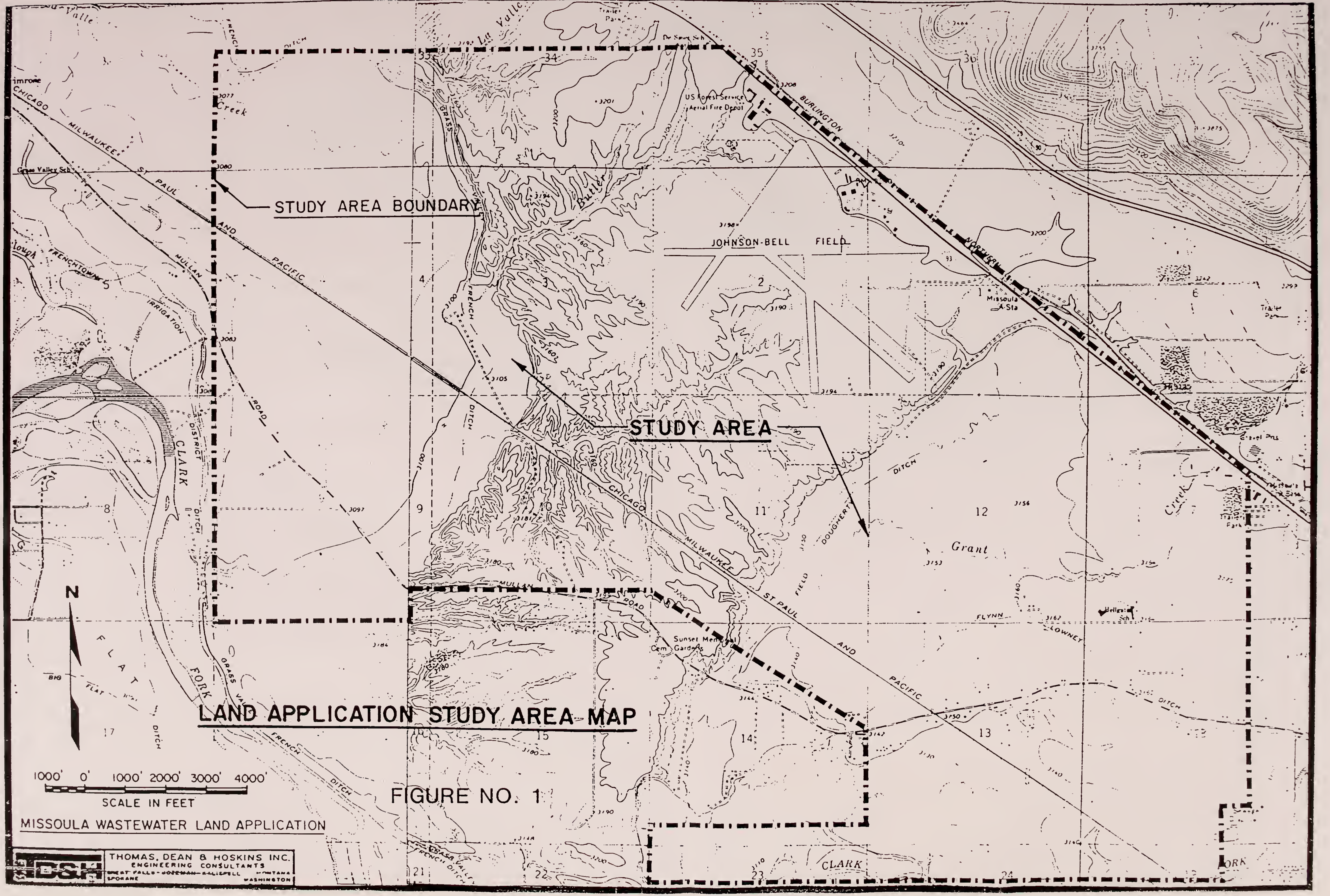


LAND APPLICATION STUDY AREA MAP

FIGURE NO. 1

MISSOULA WASTEWATER LAND APPLICATION

THOMAS, DEAN & HOSKINS INC.
ENGINEERING CONSULTANTS

SECTION II

WETLANDS

DESCRIPTION

Wetlands can be utilized for treatment of wastewater. They provide an environment wherein organisms and plant life can stabilize the organic wasteload and remove many of the by-products, including part of the nutrient load. Wetlands essentially perform as shallow facultative lagoons for stabilization of the wastewater while plant life provides oxygen for the bacteriological process and removes at least part of the nutrient load.

A wetland is generally defined as an area flooded or saturated by surface water or groundwater with sufficient frequency to support vegetation and aquatic organisms adapted to saturated soils. Natural wetlands comprise only a very small portion of the study area and are primarily located along the Clark Fork River. A small area located in the west side of the study area in Sections 4 and 9 on Butler Creek may also meet the definition of a wetland.

LAND REQUIREMENTS

There are two basic types of wetlands. One is a free water surface wetland while the other is a submerged bed wetland. The submerged bed wetland has more abundant vegetations and requires less land area for the same degree of phosphorous removal. A submerged bed wetland requires approximately 210 acres for the design flow of 9 MGD while a free water surface wetland requires approximately 366 acres.

The only significant natural wetlands lie along the Clark Fork River. The river is braided with numerous channels and islands which are generally covered with trees and brush. The largest single wetland type area is located in the southeast corner of Section 13 and is bordered by an old river meander channel. This area contains some active and some abandoned stream channels. Portions of the area are saturated while other portions are being utilized for agriculture. This area could potentially be converted into a wetland treatment system, but it is only about 110 acres in size. The area is within the 100 year floodplain and a portion is in the floodway. Floods on the river can potentially destroy any constructed wetlands in this area.

Wetlands can be constructed at other locations in the study area out of the floodplain. One potential site is in Section 12 by Grant Creek on prime farmland while another potential site is south and west of the airport. Land in the airport area would have to be terraced because of the natural ground slopes.

ENVIRONMENTAL CONSIDERATIONS

Wetlands are by definition areas that are flooded or saturated by groundwater or surface water with sufficient frequency to support vegetation and aquatic organisms adapted to saturated soils. If wastewater is discharged to natural wetlands, groundwater and surface water in the area will be impacted. Regulations requiring non-degradation of groundwater would have to be addressed as well as regulations and requirements on surface water discharges. New discharge permits would have to be obtained. In constructed wetlands, impervious liners can be placed beneath the wetlands to protect the underlying groundwater system, but this is very expensive.

Wetlands provide good habitat for waterfowl but they also provide a potential breeding place for mosquitos and other insects which can spread disease. Any construction within natural wetlands or floodplains would have to be done carefully to avoid damage by floods and to avoid increasing the flood level.

RELATED REPORTS

A report titled "Missoula Land Application Study - Preliminary Report 1" by Spratt & Associates addresses wetlands in more detail. This report is included in the Appendix.

SECTION III

IRRIGATION

GENERAL

Utilization of treated wastewater for agricultural irrigation provides one potentially beneficial method of reducing not only the phosphorous load, but the nitrogen load, biochemical oxygen demand load, and total suspended solids load on the river. Ideally, all of the wastewater generated throughout the entire year would be utilized for irrigation and none of the effluent would be discharged to the river. This option would require all wastewater produced in the non-irrigation months to be stored for disposal during the irrigation season. Storage of 6.4 to 9 million gallons of wastewater per day during the non-irrigation months, however, is not feasible because of the large amount of land required for irrigation and storage. This option is therefore not considered further.

Even though winter storage of wastewater is not feasible, removal of all or part of the total wastewater flow during the normal warm weather irrigation season is beneficial to the river since it reduces the nutrient load during the peak growing season. Four irrigation options are evaluated in this report. They are:

1. An irrigation system capable of distributing a maximum flow of 3 MGD with no storage provisions.

2. An irrigation system capable of distributing an average flow of 6 MGD with no storage provisions.

3. An irrigation system capable of distributing a total future average day flow of 9 MGD with sufficient storage available to eliminate discharge to the river during all periods of the day except for the most extreme peak flow periods.

4. A pumping system that delivers an average daily flow of 6.4 MGD of treated effluent to one of the existing irrigation ditch systems. Distribution and application would be the responsibility of the irrigatin company and individual users.

Wastewater may be utilized for irrigation provided it is adequately treated and the application is carefully controlled to prevent pollution of ground and surface waters. The wastewater must also be applied in a manner that avoids contact with people through either wind born aerosols or by direct contact, and the crop to be irrigated must not pose a potential direct or indirect threat for transmission of diseases to humans. In general, fodder, fiber, or seed type crops are preferred over food crops that are directly consumed by people. Irrigation of pastures utilized by milking cows or goats is restricted.

IRRIGATION SYSTEM TYPES

Irrigation systems can be classified into two general categories: flood and spray. Flood systems apply the water at the upper end of the site and rely on gravity to distribute the water across the site. The upper end is flooded longer than the lower end resulting in a non-uniform application and excess water must be applied to satisfactorily irrigate all parts of the site. Water that does not enter the ground is collected at the lower end of the site and is usually returned in ditches to a surface stream. Since wastewater should be carefully applied in a uniform manner to minimize the risk of leaching contaminants into the groundwater aquifer, and since excess wastewater collected at the lower end of the fields may be returned directly to the river, flood irrigation is generally not considered a desirable method of irrigation with wastewater.

Spray irrigation systems utilize pressure and nozzles to broadcast the water over the area to be irrigated. The systems may be either fixed or mobile. Fixed systems require a large amount of piping to distribute the water over the field. The piping is usually buried so that it does not interfere with the operation of farm equipment. Subsurface fixed systems are very expensive and are generally not feasible for large land areas. Some fixed systems are laid on the surface of the ground and must be removed each time the crop is harvested. This type of system is most commonly used for irrigation of small or irregular shaped areas. Labor costs for these systems can be prohibitive.

Mobile spray irrigation systems are the most economical alternative for large land areas. There are three basic types of mobile spray systems: traveling irrigation guns; wheel line systems; and center pivot systems. The traveling irrigation gun system has a large nozzle mounted on a cart that broadcasts the water typically further than 130 feet. A flexible hose connects the cart to a fixed supply line. These large guns require high pressure and shoot the water high in the air thus creating a potential problem with aerosols and wind drift. This type system is not suitable for wastewater application.

Wheel line systems utilize high pressure heads spaced at uniform intervals along a wheel mounted pipeline. The heads typically broadcast the water over a range of about 60 feet. Wind drift of aerosols can be a problem, but the overall problem is not as severe as with the traveling gun. Central power units move the system as a whole, but labor is still required to operate the power unit and make all pipeline connections with each setting. Wheel lines are fairly adaptable to various sized fields and they are compatible with rectangular property patterns. Wheel lines are particularly well suited for smaller fields and are significantly less expensive than center pivot systems.

Center pivot systems utilize irrigation heads mounted along a distribution pipeline suspended between drive units. The drive units are typically spaced from 120 to 180 feet apart. The entire line pivots around a center point which provides water for irrigation and electricity to power the drive units and control valves. The suspended line is well above the ground and the irrigation heads can either spray upward utilizing high pressure water supply or downward utilizing low pressure water supply. Downward spraying heads provide an attractive alternative for wastewater since they can reduce the potential for aerosol wind drift and require less power due to the reduced pressure.

Center pivots typically irrigate a circular pattern omitting the corners of square fields. Pivots utilize two methods for corner irrigation. One method is a special irrigation gun mounted on the end of the pivot which sprays into the corner as the pivot moves by. Another method utilizes a special extension that is activated and swings out as the pivot travels by the corner. This swing out extension is quite expensive and is only practical for large systems. Center pivots operate automatically and require no labor other than normal maintenance. Special pivot systems are available that can be towed to adjoining fields. Pivots are substantially more expensive than wheel lines to install, but require very little labor to operate. Low pressure pivot systems require substantially less electrical power for pumping than do the higher pressure pivot and wheel line systems.

EXISTING AREA IRRIGATION SYSTEMS

Hellgate Valley Irrigation Co.

This irrigation company currently serves the area closest to the treatment plant and includes the Flynn and Lowney ditches. This system draws water from the Clark Fork about one quarter mile below the point where W. Broadway crosses the railroad. The water initially flows through a pipe system and then into an open ditch system. The ditch company currently has 1700 water shares with each share representing one miner's inch of water. Forty miners inches is equivalent to one cubic foot per second (cfs). Maximum system water allotment is equivalent to 42.5 cfs.

Annual shareholder cost assessment typically varies from $1 to $2 per share depending on the anticipated maintenance needs. Water shares go with the land. When the land is sold the shares go with it. The value of a share is set by the open market. If someone wishes to sell their shares separately, the seller must negotiate a sale price. A representative of the system thought that some shares had been sold for about $50 per share a few years ago.

The president of the irrigation company indicated they are not seeking additional water. Except for rare instances in extremely dry years, they have had adequate water. Essentially all of the land is now sprinkler irrigated which has conserved a lot of water that was once used in flood irrigation. In addition, significant portions of the original irrigation district have been subdivided and no longer utilize water from the irrigation company. This leaves added water for the remaining irrigators. Sprinkler irrigation systems in the area consist of about half wheel lines and half hand set lines. There are no center pivot systems. The company experiences some problems in maintaining their diversion point from the river due to government regulations on construction in the stream bed.

Grass Valley Ditch Co,

This irrigation company serves land in the western portion of the study area and beyond. The Grass Valley ditch and Grass

Valley French ditch are operated by this company. The system draws water from the Clark Fork below the Kelly Island access site and discharges it back to the river about two miles above the pulp mill. The irrigation company has 4000 water shares with each share representing one miner's inch. Total equivalent flow is 100 cfs. The shares go with the land the same as for the Hellgate Valley Irrigation Company. Annual Shareholder cost assessment is about $6.00 per share.

Adequate water is available except in extremely dry years. The company experiences some difficulty in maintaining the river diversion point and has significant problems with algae and aquatic plants blocking or restricting flow in the ditch. They expend a significant amount of money annually for chemicals to control plant growth in the ditch. About ninety percent of the land is sprinkler irrigated with either hand set lines or wheel lines. There are no center pivot systems.

Sprinkler irrigation has conserved a significant amount of water from the original flood irrigation practices. In addition, subdivisions have removed land from agriculture and made additional water available to remaining irrigators.

Frenchtown Irrigation District

This irrigation district has about 34 miles of canals of which about half are laterals. They have a total water right for 177 cfs. The system was constructed by the federal government and is operated by the irrigation district. The water is tied to the land. The land is assessed on an area basis and operating costs are collected through a property tax by the county government. The assessment for last year was $6.00/acre.

The ditch takes off at the Kona Ranch about five miles below the sewage treatment plant. Land within the irrigation district is nearly 100 percent sprinkler irrigated - primarily with hand set lines because of the many small land parcels and irregular shapes. Some wheel lines are in use. Ditches are open from May to November but flows are turned way down after October 1st. There is currently no shortage of water. Sprinkler irrigation has conserved water and removal of farm land for subdivisions have made additional water available to the remaining irrigators. The district's primary problem is with algae and other aquatic plants plugging or restricting ditch flow.

RELATED REPORTS

A special supplementary report titled "Missoula Land Application Study, Phase I - Preliminary Evaluation of Irrigation and Crop Alternatives" by Dr. William Inskeep, a soil chemist with the Department of Plant and Soil Science at Montana State University was prepared as an aid in identifying suitable soil types, potential crops, suitable irrigation rates, crop water consumption, and probable crop utilization of nitrogen and phosphorous. Information from this report is utilized herein to screen and identify probable suitable wastewater effluent irrigation sites. Reference should be made to this report for additional details. A copy of this report is included in the Appendix.

SITE SELECTION CRITERIA

Soils

Dr. Inskeep's report recommended the following soils in order of preference:

1. DeSmet loam
2. Grantsdale loam
3. Grassvalley silty clay loam.

The Grassvalley silty clay loams are an acceptable soil, but are easily erodible. Irrigation on slopes greater than 8 percent should be avoided and slopes in the 4-8 percent range should be used cautiously with this soil type. The Moise gravelly loam can also be utilized but doesn't make prime farmland because of its poor available water holding capacity.

Crop Alternatives

Alfalfa, grass hay, or alfalfa-grass hay mixtures are recommended. These crops have substantially higher water consumptive use and higher nitrogen and phosphorous uptake than spring grains. Alfalfa and grass hay have a normal planting cycle of once every 5-7 years depending on climatic conditions. Spring grains could be utilized as a potential crop rotation between hay planting cycles.

Annual Water Application

Depending on the method of analysis, the annual consumptive use of alfalfa or grass hay could vary from 15 to 42 inches annually. A maximum application rate of 28-30 inches annually is recommended. At this rate, the applied wastewater should not adversely affect the groundwater quality even if the crop consumptive use is somewhat less. The El-Mar Estates Subdivision currently has a permit to apply a maximum of 28 inches of wastewater per year on the Grassvalley silty clay loam.

The consumptive use of spring grain crops is substantially less than alfalfa and as such is a poorer crop selection. Spring grains would have a maximum annual application of approximately 20 inches.

Application Area Size

Based on an annual application rate of 28 inches per year for a grass or alfalfa hay crop, a minimum of 1,420 acres is required for disposal of 9 MGD, 947 acres for 6 MGD and 474 acres. The application period is limited to 120 days.

Groundwater Considerations

The recommended application areas should have good soil drainage with the water table well below the ground surface. All of the phosphorous should be taken up by the crop or absorbed by the soil. The proposed crops will only remove part of the total annual nitrogen load applied, but the remainder will probably not adversely affect crop production or water quality.

Regulatory Requirements

The Water Quality Bureau of the Montana Department of Health and Environmental Sciences published spray irrigation guidelines in July of 1979 as a supplement to the requirements listed in the Ten State Standards. Some flexibility in application of these standards is permitted on a case-by-case basis. The Water Quality Bureau will not provide commentary or consider potential deviations or interpretations of these guidelines until the City of Missoula has selected specific sites and provided detailed information on those sites. A brief summary of the guidelines is as follows:

1. Fencing and Warning Signs. The site must be fenced to exclude livestock and discourage trespassing. Appropriate signs are required along the project boundaries to designate the nature of the facility and advise against trespassing. The fence requirement may be waived if appropriate.
2. Runoff. The system should be designed and operated to prevent surface runoff from entering or leaving the site.
3. Disinfection. All wastewater utilized for irrigation should receive at least secondary treatment and be disinfected. The degree of disinfection depends on the crop use as listed in Table 1.

TABLE 1
DISINFECTION REQUIREMENTS

Application	Mean No. of Coliform Organisms
Food crops	2.2/100 ml
Fodder, fiber, & seed crops	Not required if buffer zone maintained & fencing provided.
Pasture for milking cows & goats	23/100 ml

Landscape irrigation	200/100 ml
Parks & playgrounds	2.2/100 ml

4. Buffer Zones. In general, a 200 foot buffer zone is required between the irrigated land and any dwelling. If the buffer zone is not owned by the irrigating party, an easement prohibiting construction of dwellings within the buffer zone must be obtained. If the effluent is not disinfected, a 200-foot buffer zone is required between site fencing and the active irrigated zone. Wider buffer zones may be required in some instances. If a buffer zone less than 200 feet is desired, it must be justified based on: (1) the proximity of dwellings, schools, parks or other public areas; (2) prevailing wind direction; (3) expected droplet size; and, (4) degree of effluent treatment.
5. Ownership. A lease for the expected operating life of the facility is beneficial for disposal on lands not owned by the wastewater generator.
6. Wind. The irrigation system cannot be utilized when the wind is greater than 25 miles per hour.
7. Groundwater Monitoring. Groundwater quality monitoring at the irrigation site may be waived if the water table is greater than 20 feet below the ground surface.

8. Hydraulic Loading. The hydraulic loading shall be based on the wettest year in ten years.
9. Chemical Loading. The loading rate of nitrogen and other potential chemical contaminants must be justified. Groundwater aquifers cannot be degraded.

RECOMMENDED IRRIGATION SITES

The criteria utilized for selecting potential irrigation sites are as follows:

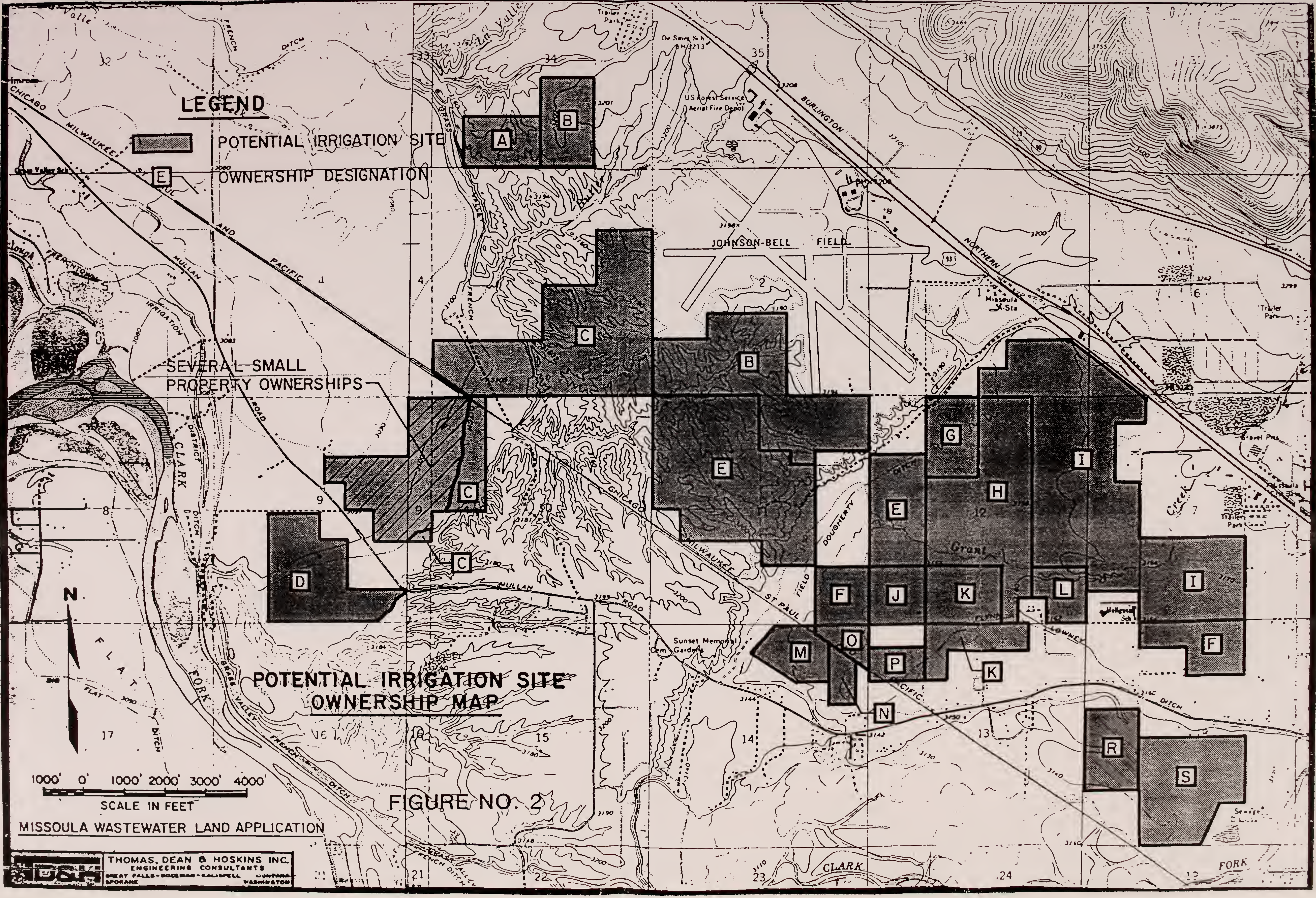
1. Soil Type. Potential sites should contain one of the soil types recommended in Dr. Inskeep's report.
2. Ownership Patterns. Developed areas or other areas that are likely to contain numerous small ownerships of 20 acres or less were excluded even though the soils may have been suitable. Subdivided and developed areas typically fall in this category. Existing development tends to concentrate in a strip fashion along existing roads. The irrigation distribution system would be difficult to administer and operate with too many small owners.
3. Buffer Zone Requirements. Buffer zone requirements tend to eliminate developed areas or areas bordering roads from consideration. In

particular, the developed strip along Mullan Road was eliminated due to probable buffer zone restrictions and the large number of small property ownerships. Small developed ownerships can be considered on a case by case basis at the option of the city. Once specific sites are selected by the city, supporting information can be submitted to the Water Quality Bureau for a determination of buffer zone requirements.

4. Location. Suitable soils are found in isolated locations south of Mullan Road and in other parts of the study area, but these were eliminated because of the potential cost of extending a distribution line to serve them. The Chicago, Milwaukee, St. Paul and Pacific Railroad right-of-way also tends to isolate some areas. Depending on the ultimate system layout, some of these areas may be serviceable at reasonable cost.
5. Topographical Features. Areas with ground slopes in excess of 15 percent are excluded because of the risk of site runoff and because the moveable irrigation equipment typically cannot operate on steeper slopes.
6. Flood Plains. Irrigation in flood plains is permitted as long as the soils are suitable for irrigation and the ground water table is deep

enough to not adversely affect crop growth or be contaminated by the applied effluent. Soils in most of the flood plain portions of the study area are not considered suitable for irrigation in Dr. Inskeep's report.

Recommended potential irrigation sites are shown on Figure 2. Identification letter shown on parcels in Figure 2 reference the property owner in the ownership table in the Appendix. More than 2,500 acres of potentially acceptable sites are identified in Figure 2 even though only 1,420 acres are required for disposal of 9 MGD, approximately 947 acres for 6 MGD, and 474 acres for 3 MGD. The entire 2,500 acres will not be needed, but at this time, there is no way to determine which land parcels will actually be obtainable for irrigation. It is unlikely that all of the preferred land will be obtainable. In addition, portions of the recommended sites may not be usable because of: (1) buffer zone requirements; (2) local areas where the ground slope may be too steep; (3) the presence of surface streams or ditches which may restrict the use of spray irrigation; or, (4) land ownership patterns that may prevent the installation of reasonably sized spray irrigation systems.



POTENTIAL IRRIGATION SITE OWNERSHIP MAP

FIGURE NO. 2

MISSOULA WASTEWATER LAND APPLICATION

THOMAS, DEAN & HOSKINS INC.
ENGINEERING CONSULTANTS
GREAT FALLS - BOZEMAN - KALISPELL MONTANA
SPOKANE WASHINGTON

IRRIGATION SYSTEM

General

Four irrigation options are considered:

1. An irrigation system capable of pumping and distributing a constant flow of 3 MGD. All flow in excess of 3 MGD will be discharged to the river.
2. An irrigation system capable of pumping and distributing an average daily flow of 6.0 MGD. No storage will be provided to eliminate discharge to the river during peak flow periods, but the system will have a peak pumping capacity of 8 MGD in order to average 6 MGD daily with low night time flows of 4 MGD. Excess flow during peak diurnal flow periods will be discharged to the river.
3. An irrigation system capable of pumping and distributing an average day future flow of 9 MGD. Sufficient storage is included to eliminate discharge to the river during all periods of the day except for the most extreme diurnal flow periods. This option provides capacity for future growth of the City of Missoula.
4. An irrigation system that merely pumps the existing average day flow of 6.4 MGD to the Flynn/Lowney ditch. The system would have a peak pumping capacity of 8 MGD. Excess water will be discharged to the river. The irrigation ditch

company will be responsible for the transport and distribution of the wastewater and for meeting all regulatory requirements and testing.

The wastewater under all options is assumed to be disinfected prior to pumping from the treatment plant. This will help minimize buffer zone requirements and also ease other potential restrictions on transport and handling of the wastewater.

TABLE 2
WASTEWATER FLOWS & PUMPING RATES

DESIGN FLOWS

Flow Condition	Option No.1 (MGD)	Option No.2 (MGD)	Option No.3 (MGD)	Option No.4 (MGD)
Peak Plant Wastewater Flow	14.0	10.5	10.5	10.5
Average Plant Wastewater Flow	9.0	6.4	6.4	6.4
Minimum Plant Wastewater Flow	4.5	4.0	4.0	4.0
Peak Pumping Rate	11.0	8.0	3.0	9.0
Average Pumping Rate	9.0	6.0	3.0	6.4
Minimum Pumping Rate	4.5	4.0	4.0	4.0

TABLE 3
IRRIGATION APPLICATIONS

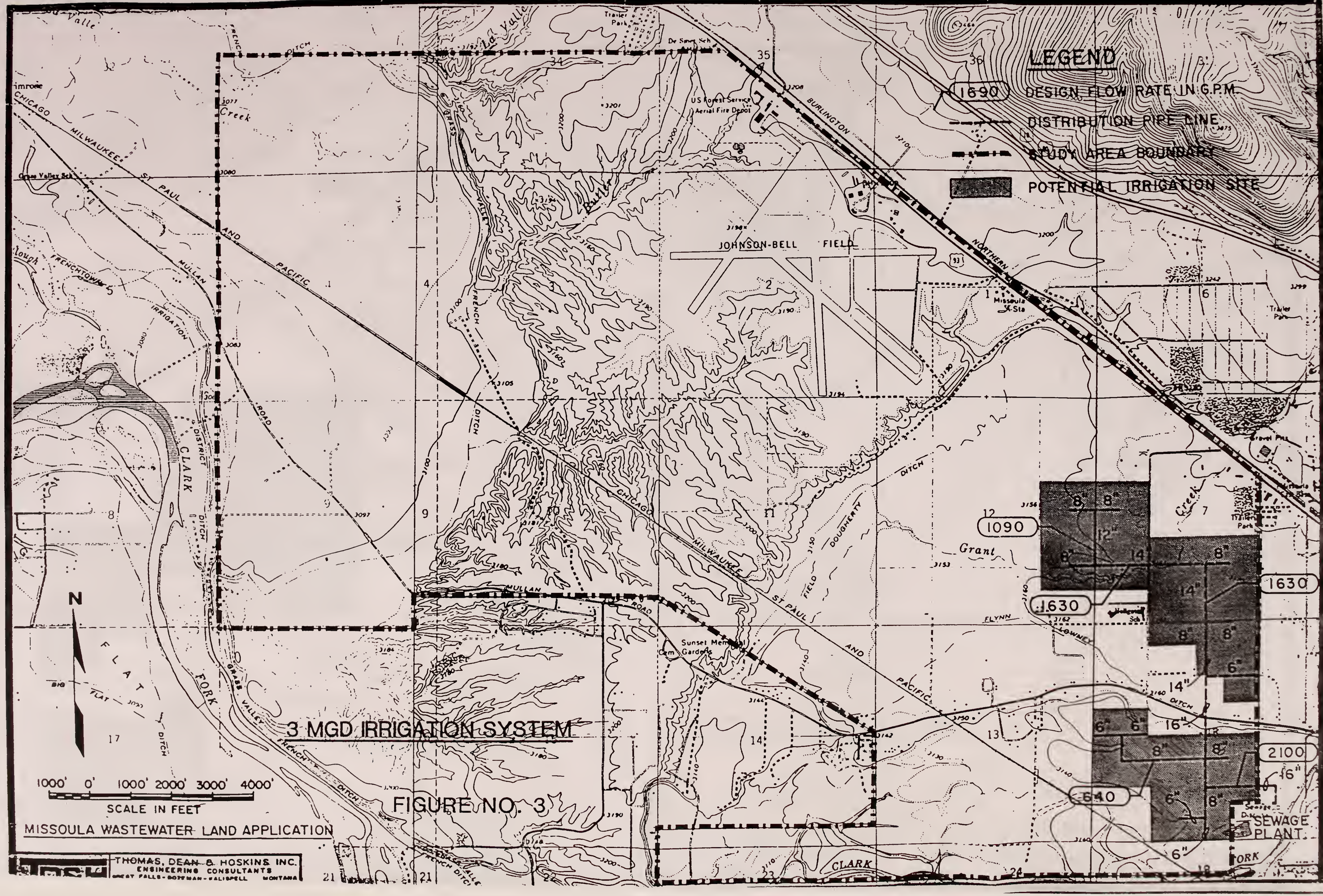
SOIL	APPLICATION RATE	TOTAL AMOUNT PER APPLICATION
DeSmet Loam	1.2 in./hr.	4.5 inches
Grantsdale Loam	1.0 in./hr.	4.5 inches
Grassvalley Silty Clay Loam	0.26 in./hr.	4.5 inches

Total Annual Application:	28 inches
Number of Irrigation Cycles:	6
Maximum Velocity in Pipelines:	4 ft./sec.

Distribution System Layout

A potential irrigation distribution system layout is shown on Figure 3 for the 3 MGD system; Figure 4 for the 6 MGD system; Figure 5 for the 9 MGD system; and Figure 6 for the Flynn/Lowney Ditch System Option. Primary and optional irrigation sites for the 9 MGD system areas are shown on Figure 5. The primary irrigation area contains approximately 1,640 acres of potential irrigation sites. Since these sites are closest to the plant, they are the least costly to serve. The optional irrigation sites should only be utilized as necessary to replace land in the primary service area that is not obtainable for irrigation.

All of the individual sites required for effluent disposal cannot be irrigated simultaneously since the total wastewater flow rate is inadequate for such an operation. Instead, some sites will be irrigated while others are being rested. Only a select number of sites in each distribution sub-system should be simultaneously irrigated in order to disperse the hydraulic load and permit utilization of smaller pipe lines. Once a set amount of water is applied to a site, irrigation at that site would cease, and another site would begin irrigation. Each irrigation site will receive about 6 irrigation cycles each year. The City, as system manager, would have to coordinate irrigation throughout the entire system so individual sub-systems would not be overloaded and so demand would not exceed the supply.

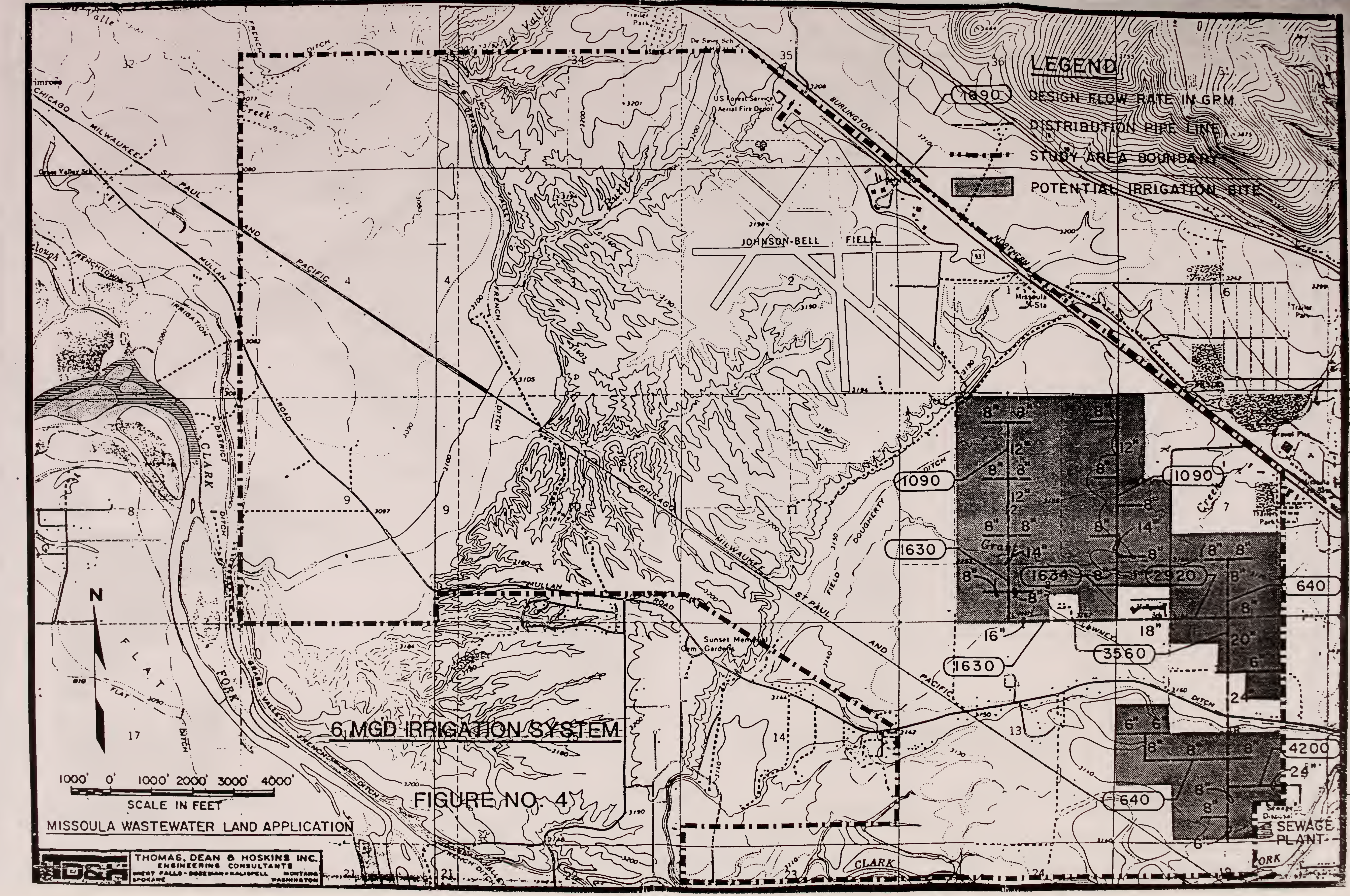


3 MGD IRRIGATION SYSTEM

FIGURE NO. 3

MISSOULA WASTEWATER LAND APPLICATION

THOMAS, DEAN & HOSKINS INC.
ENGINEERING CONSULTANTS
GREAT FALLS-BOZEMAN-KALISPELL MONTANA

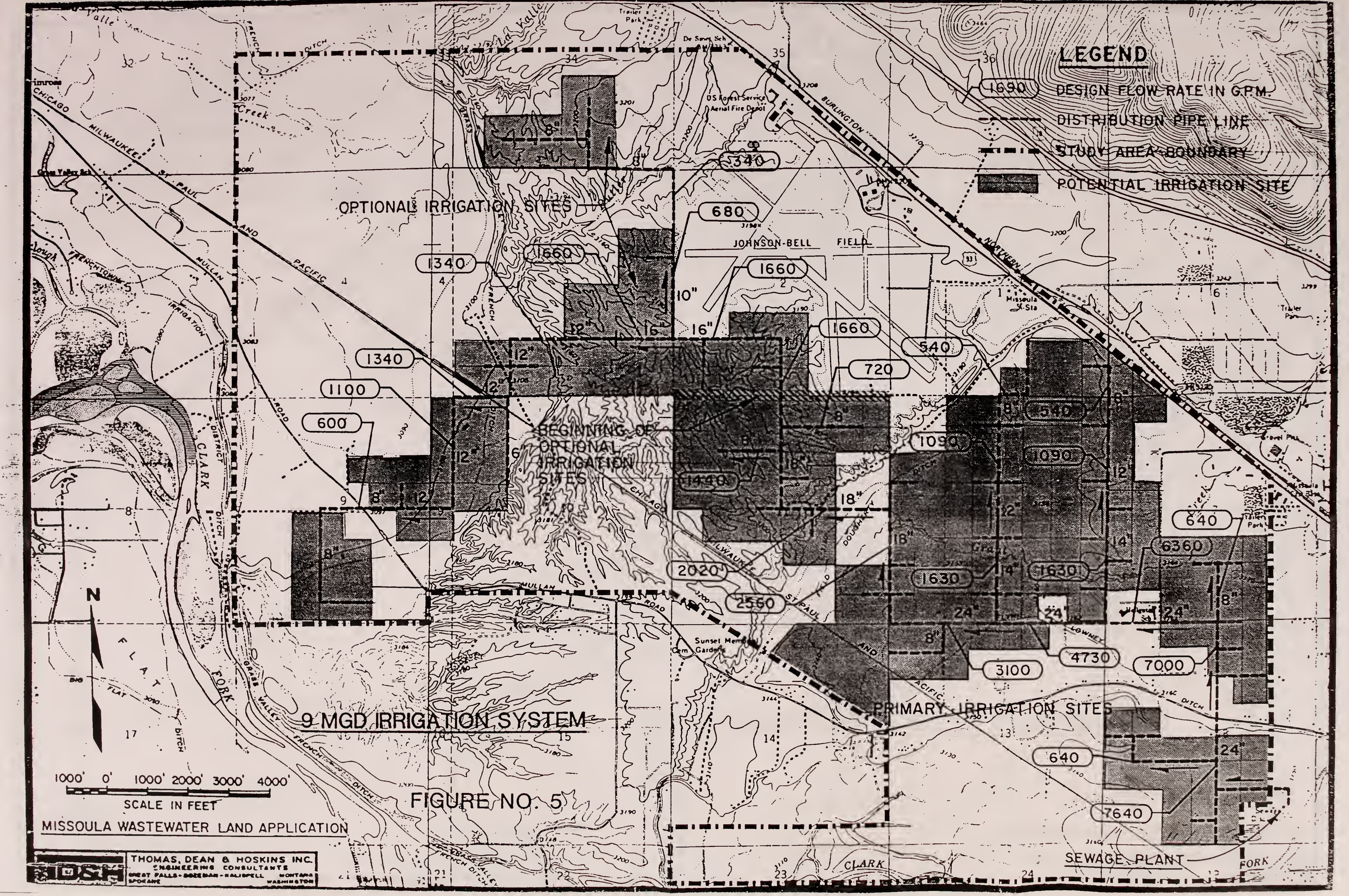


6 MGD IRRIGATION SYSTEM

FIGURE NO. 4

MISSOULA WASTEWATER LAND APPLICATION

THOMAS, DEAN & HOSKINS INC.
ENGINEERING CONSULTANTS
GREAT FALLS - BOZEMAN - KALISPELL MONTANA
SPOKANE WASHINGTON



9 MGD IRRIGATION SYSTEM

FIGURE NO. 5

MISSOULA WASTEWATER LAND APPLICATION

THOMAS, DEAN & HOSKINS INC.
ENGINEERING CONSULTANTS
GREAT FALLS - BOZEMAN - KALISPELL MONTANA
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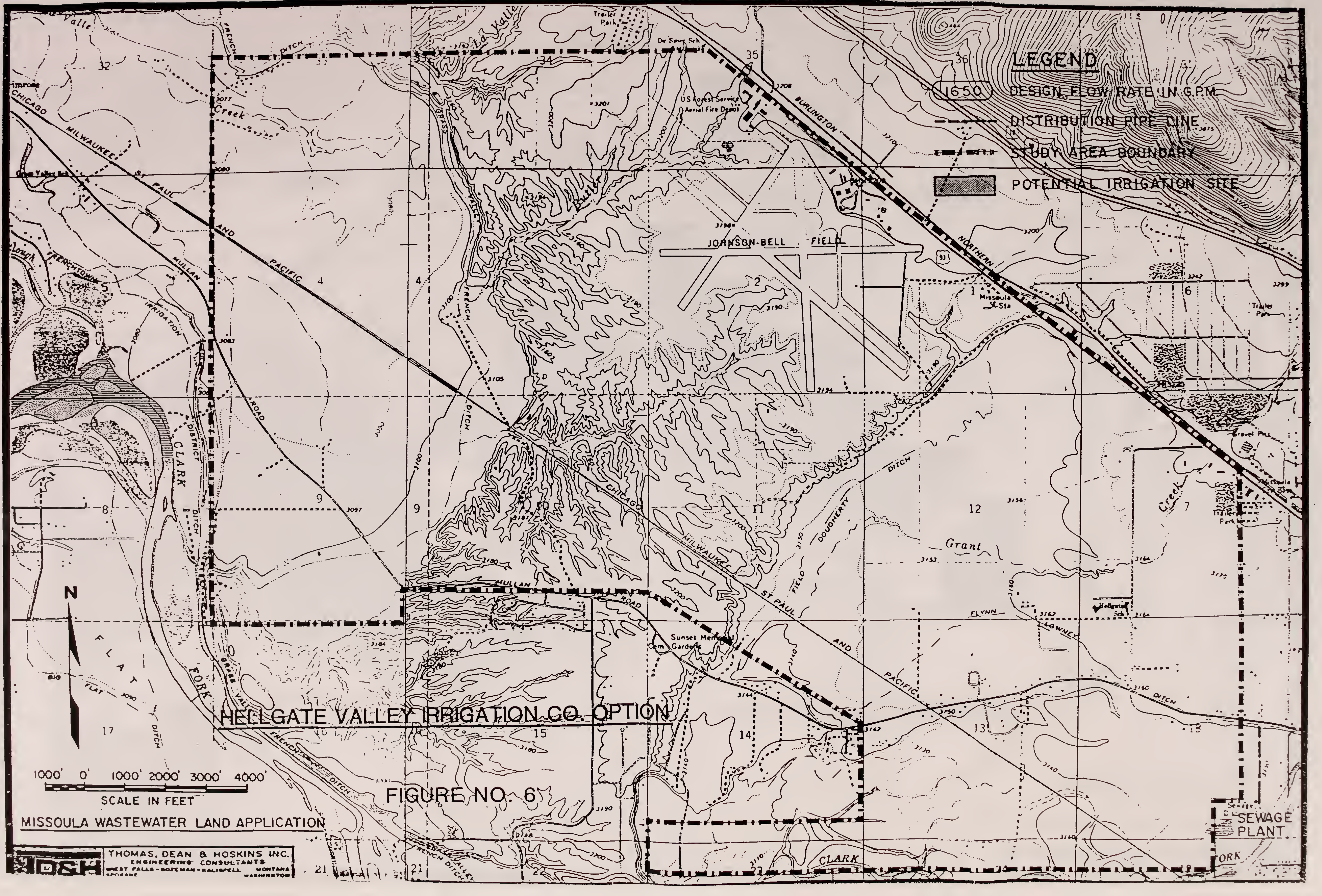


FIGURE NO. 6

MISSOULA WASTEWATER LAND APPLICATION

THOMAS, DEAN & HOSKINS INC.
ENGINEERING CONSULTANTS
GREAT FALLS - BOZEMAN - KALISPELL MONTANA
SPOKANE WASHINGTON

Spray System Selection

Utilization of Existing Irrigation Systems.

Almost all of the proposed irrigation sites except for those sites on the higher ground south and west of the airport are currently sprinkler irrigated. A lot of the irrigation is done with hand set irrigation lines. The larger individual blocks are typically irrigated with wheel lines. There are currently no center pivot systems believed to be in use. The most economical option for the city is to simply deliver the water to specific points and then let the individual farmers install the necessary connecting systems to utilize the treated wastewater. Each individual farmer would be responsible for his own irrigation within the restrictions of an overall irrigation schedule established by the city. The cost to individual farmers may vary widely depending on the modifications they must make in their existing systems to utilize the water. Some individuals may have difficulty in negotiating an irrigation schedule that is compatible with their needs and the city's distribution system needs.

Installation of New Irrigation Systems.

The city may be able to obtain more interest and better participation from local farmers if they were to participate in the cost and installation of new labor saving sprinkler systems. Farmers currently utilizing hand set systems may be particularly interested.

The ownership pattern shown on Figure 2 illustrates that large single block ownerships suitable for large center pivot systems do not exist. Instead, the area will probably have to be irrigated in 40 acre parcels with a few 120 acre systems unless agreements can be made to assemble single large blocks. Center pivot systems are recommended because of their lower operating labor costs, although they would be disproportionately expensive if sixteen 40-acre block systems were utilized to irrigate a single 640-acre block instead of one larger pivot. Because of the large number of 40-acre systems, a single towable pivot unit is recommended to serve more than one tract where suitable adjacent 40-acre tracts exist. Although towable units reduce the initial equipment cost, they also increase the potential system operating cost because of the labor required to move the units and increased maintenance.

Owners may object to unirrigated corners common to center pivot systems, and provision may have to be made for corner irrigation guns or hand set lines which require higher pressure for operation. An irrigation system utilizing only low pressure center pivot systems that spray downward is the most desirable because of significantly reduced electrical energy costs and because of reduced potential for aerosol problems. Wheel lines, hand set lines or pivot systems requiring higher pressure cannot be utilized in conjunction with low pressure center pivot systems unless booster pumps are installed wherever higher pressures are required. Wheel lines and hand set lines will have to be utilized in some areas in order to fit the available field shape.

Pumping Requirements

A pump station is required to pump water from the treatment plant to the individual spray irrigation systems. A system utilizing low pressure pivot systems that operate at pressures 30-35 psi less than comparable high pressure systems will significantly reduce power costs. If the irrigation system includes sites on the higher ground in Section 11 just south of the airport the main plant pump station will have to develop sufficient pressure to at least operate a low pressure center pivots in this higher area. An alternative is to construct a booster station on the main line to serve the higher irrigation sites in Sections 2, 3 and 11. Ultimately, the benefit of a booster station for these areas will have to be weighed against the potential savings in total pumping costs. Individual booster pumps may have to be utilized for wheel line systems or hand set systems for the 9 MGD option in some areas in order to achieve satisfactory operating pressures.

Disinfection

Wastewater utilized for irrigation will be disinfected. This is required in order to avoid or at least minimize buffer zone requirements and in order to by-pass part of the excess water flow to the river during peak flow periods. The amount of treated wastewater that must be discharged to the river will vary widely depending on the irrigation option selected. Buffer zones waste productive land and are regarded unfavorably by most irrigators.

Storage

Short term peak wastewater flows of 14 MGD are expected at the treatment plant under the 9 MGD Option. Addition or deletion of individual spray irrigation systems to match short term peak flow variations is impractical. Unless the flow can be sustained for at least six hours, there is little benefit in trying to match the flow with the irrigation system. As such, the excess water during peak flow periods will have to be disinfected and sent directly to the river or it must be stored and pumped when the overall flow is lower. Sustained flows of 11 MGD appear probable in the future when the average daily flow is 9 MGD. A 500,000 gallon storage tank would probably be adequate for storing short term peak flows up to 14 MGD without discharge to the river. A 500,000 gallon tank with associated pumping equipment was assumed to be an integral part of the 9 MGD option but not for the 3 MGD and 6 MGD options. During extremely wet weather, irrigation may have to be terminated and disinfected water sent directly to the river unless a 70 to 100 million gallon storage facility is constructed. Storage can be eliminated in favor of direct stream discharge provided future discharge permits continue to permit stream discharge without requiring phosphorous removal.

COSTS

General.

The potential cost of a wastewater effluent irrigation system varies widely depending on a number of factors and questions which are beyond the scope of this report but which must be resolved before a single specific probable cost estimate can be made. These questions include:

1. What amount of water is to be disposed of each day?
2. Can excess water be discharged to the river or will storage be required for peak flow periods?
3. Will the City purchase new spray irrigation equipment or will farmers utilize their existing equipment?
4. Will the spray irrigation systems require high or low pressure operation?
5. Will the City be involved in the operation of the spray irrigation equipment or will this be left entirely to the farmers?
6. Will the City purchase land or rely on leases with the individual farmers to dispose of the water?
7. Where is the exact location of the irrigation sites?
8. Will the farmers charge the City a fee to accept and dispose of the water?
9. Will the farmers be willing to pay the City a fee for use of the water because of the nutrients in the wastewater?
10. Are any of the existing ditch companies willing to accept the water and distribute it through their ditch system?
11. What requirements will the Water Quality Bureau ultimately place on the final system?

In order to provide guidance for initial decision making, probable construction and operation and maintenance costs are provided for each of the four basic irrigation options being considered based on certain assumptions. Final conditions and deviations from these assumptions can significantly affect the probable cost.

Assumptions

3 MGD Option. This option represents the probable cost of a minimal irrigation system. The minimum wastewater flow at the treatment plant is greater than 3 MGD, therefore, the pumping rate can be constant throughout the 24 hour period. Storage of excess wastewater is not provided. Excess water will be discharged to the river. Costs are based on serving the sites shown on Figure 3. If the system must be extended further to find farmers willing to accept the water, then construction costs will be increased. Operating power costs are estimated for a high pressure delivery system suitable for wheel line or hand set systems.

6 MGD Option. This option represents the probable cost of disposing of most of the existing daily wastewater flow through irrigation. Storage of short term peak flows is not provided. Excess water will be discharged directly to the river. Costs are based on serving the sites shown on Figure 4. If the system must be extended further to find farmers willing to accept the water then construction costs will be increased. Operating power costs are for a high pressure delivery system suitable for wheel line or hand set systems.

9 MGD Option. This option represents the probable cost required for irrigation disposal of an average daily future wastewater flow of 9 MGD. Storage of short term daily peak flows was included in the estimates although it may or may not be ultimately required. Costs for extended storage of all flow during the winter or during wet weather periods have not been included. The basic cost estimate prepared for this option assumes that sufficient land can be obtained by the City for irrigation within the primary irrigation area designated on Figure 5. If sufficient land cannot be obtained within the primary irrigation area, then the system will have to be extended to the optional irrigation areas further to the west. The probable construction cost will increase as the system is extended to the western part of the study area. If the system were required to utilize all of the optional irrigation areas as shown on Figure 5, the probable construction cost could increase by approximately $1,500,000 above the costs shown for the basic irrigation area.

The assumption is made in calculating operating costs that the system will only produce enough pressure to operate a low pressure center pivot system at the western edge of the primary service area. If the system must be extended to the optional service areas by the airport or to the western side of the study area, the electrical energy operating costs will increase significantly. Likewise, if higher pressure spray irrigation systems are utilized rather than low pressure center pivot systems additional costs will be incurred for electrical energy and a main line booster pump station will probably be required. The cost of a new booster pump station would have to be weighed against the increased energy costs for higher pumping pressures at the treatment plant. The location of actual sites must be known before a decision can be made on the need for a booster pump station on the main distribution line. Local individual booster pumps will probably be required in some areas regardless of the main line requirements.

Hellgate Valley Irrigation Co. Option This option represents a typical cost to simply deliver an average daily flow of 6.4 MGD to the Flynn/Lowney ditch which is owned and operated by the Hellgate Valley Irrigation Co. This is the closest existing irrigation ditch system to the treatment plant and represents the least possible cost for irrigation. The water is simply delivered to the ditch. No costs are included for distribution or operation of the irrigation systems. The only operating and maintenance costs considered are for the operation and maintenance of the pump station at the wastewater treatment plant. Electricity costs are for the minimum pressure required to deliver the water to the ditch. The pressure is not adequate for the operation of any type of sprinkler system. Testing and monitoring costs are assumed to be covered by the irrigation company.

Probable Costs.

Two separate construction cost estimates and two operation and maintenance cost estimates are provided for all options except Option 4. One estimate is for the basic delivery system that distributes the water to the various spray irrigation systems and includes the cost of the pumping facilities at the treatment plant. The other estimate included the cost of spray irrigation equipment needed to apply the wastewater. This equipment may not be needed if each individual farmer provides his own equipment.

In addition to the two construction cost estimates, two operation and maintenance cost estimates are provided for each of the first three options. One estimate includes only the cost of operating the pumping facilities at the treatment plant and providing general administration and coordination of the irrigation system. A separate operating and maintenance cost estimate is provided for operation of the center pivot irrigation systems. This estimate assumes the City will provide the equipment and part of the labor to maintain the equipment and tow the center pivot systems between fields. Each individual farmer is assumed to aid in maintenance of the pivots and assist in moving them. The estimates also assume each farmer will provide all labor required to move and operate all wheel line or hand set systems utilized in his own fields.

A 20 year planning period is utilized since this is a reasonable life cycle over which to compare operating costs.

Most mechanical equipment items will have a useful life of about 20 years. Items such as pipelines will have a probable useful life of 50 years or more. The cost of labor and electrical energy is assumed to double within the 20 year planning period. Annual operation and maintenance costs are presented in terms of their current present worth which is a good method of comparing the operating cost of the various alternatives over a period of time. Present worth represents the amount of money that would have to be invested at the beginning of the operating period at a specific interest rate to cover the operation and maintenance costs for the entire planning period. An interest rate of 8% is utilized for the 20 year planning period. The sum of the construction cost plus the present worth of the operating and maintenance costs is the best way to compare the true cost of different alternatives.

The probable construction costs for each alternative plus the present worth of the annual operation and maintenance costs are summarized in Table 4. As previously discussed, two separate estimates are provided for each option so that the spray irrigation system costs are separated from the delivery system costs.

TABLE 4				
COST SUMMARY				
DESCRIPTION	OPTION 1	OPTION 2	OPTION 3	OPTION 4
	3 MGD SYSTEM	6 MGD SYSTEM	9 MGD SYSTEM (PRIMARY SITES)	HELLGATE VALLEY IRRIGATION COMPANY
DELIVERY SYSTEM				
CONSTRUCTION COST	1,785,020	2,591,850	4,332,390	1,019,250
O&M PRESENT WORTH COST (@ 8% FOR 20 YEARS)	313,930	564,290	747,300	234,400
SUBTOTAL	2,098,950	3,156,140	5,079,690	1,253,650
SPRAY IRRIGATION SYSTEMS				
CONSTRUCTION COST	255,500	479,000	1,534,900	N/A
O&M PRESENT WORTH COST (@8% FOR 20 YEARS)	149,000	169,110	394,700	
SUBTOTAL	404,500	648,110	1,929,600	
TOTAL COST OF COMPLETE SYSTEM	$2,503,450	$3,804,250	$7,009,290	$1,253,650

INCOME POTENTIAL

If circumstances are right, treated wastewater can be an asset that has monetary value. Wastewater is not only a source of water but it is also a source of nutrients - particularly phosphorous and nitrogen. In areas where water supplies are scarce, treated wastewater is of value simply for the water. This does not appear to be the case in the Missoula valley. Representatives from three irrigation companies in the area all indicated they had adequate water supplies and they did not need additional supplies. Almost all irrigation is now done with some form of spray irrigation which utilizes substantially less water than flood irrigation. Since irrigation districts were originally set up for flood irrigation, the switch to spray irrigation has reduced overall irrigation demand. In addition, rural subdivisions are removing irrigated land from production which has also reduced the demand for irrigation water by the irrigation companies. The irrigation companies only rarely experience water shortages. Shortages only occur when the river flow is severely reduced during extreme drought years.

Some of the irrigation companies indicated they had difficulty in maintaining their river diversion structures which could be a potential reason for considering an alternate source. There is insufficient wastewater, however, to totally replace all of the required water currently being diverted by any of the irrigation companies. Use of the wastewater would therefore not replace the need for the companies to maintain their existing river intakes.

Wastewater does contain nutrients which have a potential value that varies depending on the type of crop being irrigated and fertilized. Based on the maximum nutrient uptake for the three basic recommended crops in Dr. Inskeep's report, the wastewater would have the following value when applied to a crop:

Alfalfa

Nitrogen:	$41.04 per acre
Phosphorus:	$ 7.92 per acre
Total	$48.96 per acre

Grass Hay

Nitrogen:	$28.50 per acre
Phosphorous:	$ 6.60 per acre
Total	$35.10 per acre

Spring Grain

Nitrogen:	$13.30 per acre
Phosphorus:	$ 2.86 per acre
Total	$16.16 per acre

Values are calculated utilizing current material prices for the equivalent amount of dry fertilizer. The value of alfalfa is misleading since it assumes nitrogen would be purchased and applied in a quantity equivalent to that found in 28 inches of effluent per year. This is unlikely since alfalfa can meet most of its own nitrogen needs through the ability of its root system to fix atmospheric nitrogen, but it does require phosphorus and will utilize some other nitrogen when available.

Irrigators may or may not be interested in the nutrient value of the wastewater. Two of the ditch companies currently experience severe problems with their ditches being plugged by algae and other aquatic plants. These companies utilize chemicals to control the plant growth at sumbstantial cost and representatives indicated they would be very concerned about the adverse impact of nutrient laden water in their ditch systems. The companies would probably not be interested in accepting the wastewater.

Existing irrigation companies currently serve all the agricultural land in the area. Shares in these companies automatically go with the land unless sold to a new owner in a separated transaction. Any landowner wishing to utilize wastewater for irrigation would still be liable for all annual assessments from the original irrigation company even if the wastewater is delivered in an independent piped system. This will reduce the attractiveness of the wastewater as an alternative water source for irrigation.

One landowner with land in the vicinity of the airport indicated he would only consider taking the wastewater if the City paid him to take it. He has been approached by subdivisions in the area to take their wastewater, but he has declined unless he was paid. He indictated there are so many long term restrictions on the crops and on the land that it effectively decreases that value of the land. He had offered to take wastewater for one subdivision at a price of $10 per residence per month. At this equivalent price, the City of Missoula would have to pay approximately $8,400 per day to dispose of the effluent through irrigation. Obviously there would probably be a substantial reduction in price due to quantity available, but it does illustrate current probable attitudes toward wastewater irrigation. The City would probably not be able to charge a fee for the water. Some landowners that currently pay pumping costs may be interested if the system eliminated their pumping costs.

SECTION IV

RAPID INFILTRATION

GENERAL DESCRIPTION

Rapid infiltration typically involves the construction of shallow earthen basins which are flooded on repetitive cycles. The water is allowed to percolate out of the basin and the basin is generally allowed to dry for a period before the next flooding cycle is initiated. The percolate is either allowed to enter the natural groundwater system or it is recovered by a subdrain system or a series of wells.

The percolate is generally of good quality. The total suspended solids, the biochemical oxygen demand, and the coliform organisms are almost entirely removed. Phosphorous removal typically runs 70-90 percent while nitrogen removal typically runs only 30 percent. Special operating procedures can be utilized to help improve nitrogen removal, but these may adversely affect overall hydraulic performance. Phosphorous is primarily removed by adsorption with some chemical precipitation. Contaminant removal is generally related to residence time and travel distance.

Rapid infiltration systems are typically loaded at higher hydraulic rates than comparable agricultural irrigation systems and require substantially less land for disposal of the effluent. The hydraulic loading rate is limited by the least permeable soil layer in the application area and by the degree of water table mounding caused by the applied water. The water table must increase in elevation or mound sufficiently to move the water away from the application point. If the resultant mound is large enough to intercept the ground surface, the system will fail since it is hydraulically incapable of moving the water from the application area.

Rapid infiltration systems are carefully reviewed and controlled by regulatory agencies. Regulations prohibit the degradation of groundwater aquifers. Percolate from rapid infiltration systems will add potential contaminants to the groundwater aquifer unless impermeable barriers exist above the aquifer or the percolate is recovered.

RELATED REPORTS

A preliminary technical report titled "Missoula Land Application Study, Phase I, Task C - Rapid Infiltration Alternative" by Spratt & Associates analyzed the potential for rapid infiltration within the study area. This report is included in the Appendix and contains detailed information on hydraulic capacity, mounding, and contaminant plumes for one potential site.

SITE SELECTION

Site Requirements

1. Sites should have a minimum saturated vertical permeability in the most restrictive soil layer of at least 0.6 inches per hour.

2. The water table should be at least 10 feet below the ground surface and the projected water table mound should remain well below the ground surface.

3. The general ground slope should be less than 10 percent and preferably less than one percent. The steeper the slope, the more expensive it is to construct a system.

4. The site should be located well away from domestic wells to reduce the risk of contamination. Sites relatively close to the river are desirable since they tend to reduce the risk of downstream well contamination.

Area Requirements

The application area size is controlled by the permeability of the most restrictive soil layer and by the degree of water table mounding. The DeSmet loam, the Grantsdale loam, and the Moise gravelly loam all have permeabilities that are generally compatible with rapid infiltration systems. The Grass Valley silty clay loam which makes up a large part of the planning area has a permeability that is too low.

An application area of approximately 230 acres is required based on the following parameters:

1. Design flow of 9 MGD.
2. Minimum saturated vertical permeability of 0.6 inches per hour in the most restrictive soil layer.
3. Allowable application rate of 43.8 feet per year.

Additional land is required for construction of basin dikes. A site approximately 300 acres in size is required for the complete facility provided the site is relatively flat. Sites on steeper slopes require more area and more earthwork for construction of the basins.

Regulatory Requirements

Whenever percolate will enter the groundwater system, an analysis must be made to demonstrate the percolate will not adversely impact the existing aquifer. Three key regulations potentially apply to this facility:

1. Non-Degradation. The percolate cannot degrade or increase the level of contaminants within the existing groundwater system.

2. Sole Source Aquifer. Groundwater in this portion of the Missoula Valley has been designated a sole source aquifer. All federally funded projects that would impact the aquifer must be reviewed by the Environmental Protection Agency for contamination potential

3. Floodplain. Floodplain management regulations prohibit the construction of sewage treatment facilities in a floodplain.

SELECTED SITE EVALUATION

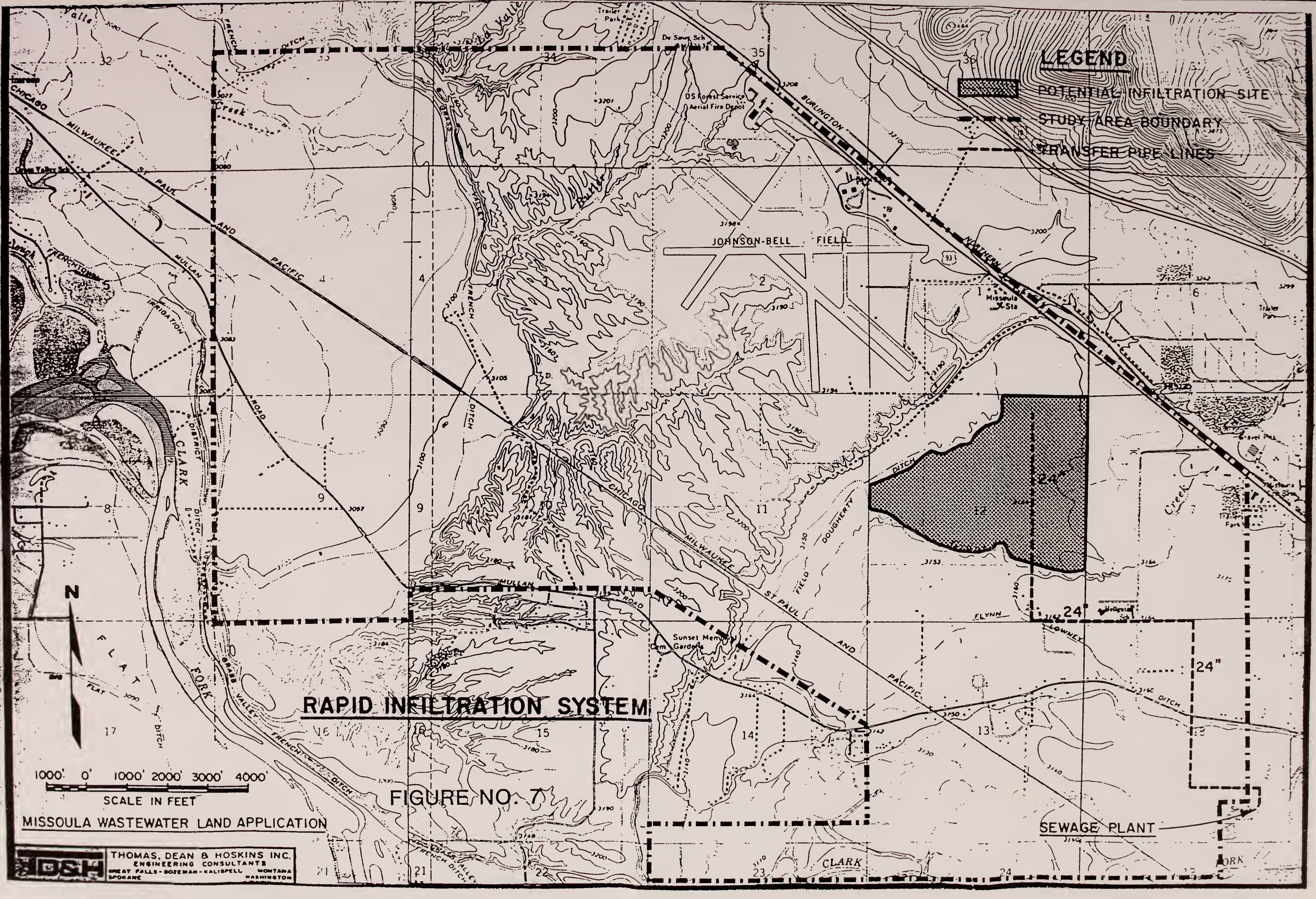
One potential site was evaluated in detail. This site is shown on Figure 7. A computer analysis was made to determine the probable water table mound and contaminant plume after two years of continuous operation. The analysis projected a maximum increase in the water table elevation of 2.8 feet beneath the proposed rapid infiltration beds.

A contaminant analysis was made assuming the contaminants would remain in solution and not be chemically or biologically removed by the soil system. This analysis indicated that contaminant concentrations would be reduced to 60 percent of their original value by the time they reached the Clark Fork River system. In reality, the contaminants such as phosphorous will be substantially reduced below that amount since they will be removed by adsorption and chemical reaction as the water moves through the soil system. Phosphorous concentrations will probably be less than 1 mg/l by the time the percolate reaches the river. Total nitrogen will probably be less than 10 mg/l. The phosphorous load on the river will probably be reduced from approximately 38 tons per year to 9 tons per year if the system were operated on a year round basis.

POTENTIAL SYSTEM LAYOUT

A potential transfer pipeline route and rapid infiltration system basin layout are shown on Figures 7 and 8. A new pumping station is required at the treatment plant to pump water to the application area from the end of the chlorine contact basin. The facility should be designed to pump short term peak flows up to 14 MGD and an average daily flow of 9 MGD. A peak flow capability of 14 MGD should be adequate for almost all peak flows and essentially eliminate direct discharge to the river. A 24-inch transfer pipeline is recommended if the facility is utilized for less than 6-8 months each year. If the facility is going to be utilized year round, a 30-inch transfer pipeline is recommended since the annual savings in power will justify the cost of the larger pipeline.

The proposed basin laid out in Figure 8 assumes each cell has bottom dimensions of 250' x 500'. Approximately 81 cells are

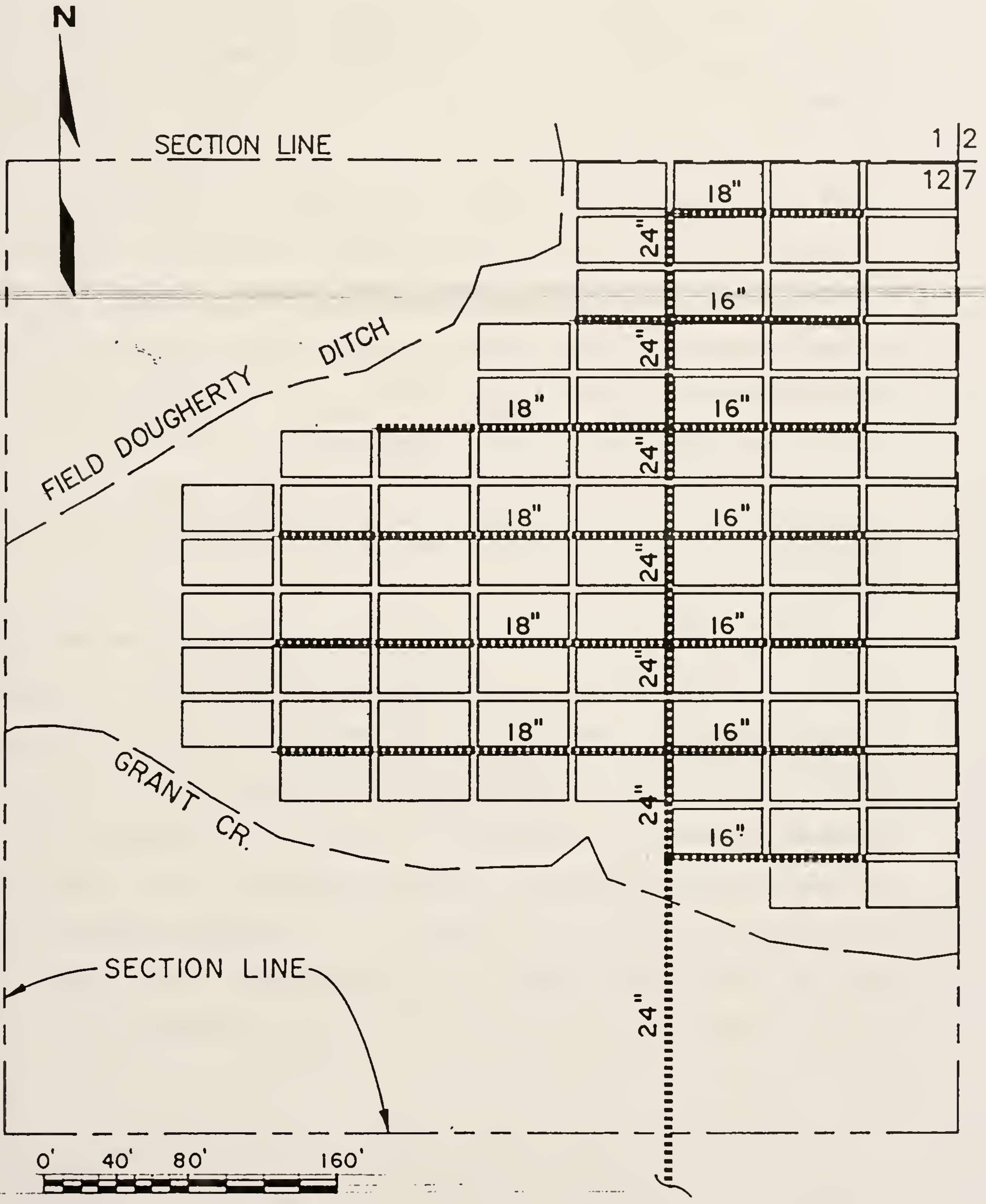


RAPID INFILTRATION SYSTEM

FIGURE NO. 7

MISSOULA WASTEWATER LAND APPLICATION

THOMAS, DEAN & HOSKINS INC.
ENGINEERING CONSULTANTS
GREAT FALLS - BOZEMAN - KALISPELL MONTANA
SPOKANE WASHINGTON



RAPID INFILTRATION SYSTEM LAYOUT

MISSOULA WASTEWATER LAND APPLICATION

FIGURE NO. 8

TD&H THOMAS, DEAN & HOSKINS INC.
ENGINEERING CONSULTANTS
GREAT FALLS - BOZEMAN - KALISPELL MONTANA
SPOKANE WASHINGTON

required for disposal of the effluent. With this many cells, remotely controlled electric actuated control valves are recommended for controlling flow to the basins. Remote control from a local control building located on site and from the main treatment plant control center is desirable. A building on site is recommended for controls and storage of maintenance equipment.

The site shown on Figure 7 requires approximately 300 acres of land between Grant Creek and the Field Dougherty Ditch. Groundwater monitor wells will have to be installed around the site and the area must be fenced and signed. An access road must be constructed. Soils on this site are among the best agricultural soils in the area, and the land will quite likely be expensive.

The site will have to be planted to grass for dust and weed control. Grass suitable for high water applications is required within the basins. The site will have to be mowed and the grass removed on a regular basis. A full time operator will be required for mowing and removal of the grass plus general control and operation of the ponds. Groundwater sampling and testing are also required on a regular basis. The sampling frequency and type of tests will have to be negotiated with regulatory agencies. Some types of tests can be quite expensive.

COST

The probable construction cost for the proposed site is estimated at $7,277,000. Land costs may add an additional $1,050,000 or more to the total project cost. The annual operating cost is estimated at $69,700. Copies of the construction cost and operating cost are included in the Appendix.

SECTION V

SUMMARY

WETLANDS

Treatment of the wastewater in a wetlands system requires substantially more wetland area than is naturally available in the study area. Wetlands would have to be constructed. This option would be difficult to implement because of land requirements and requirements the system would have to meet relative to the non-degradation of surface and groundwater systems.

IRRIGATION

Utilization of treated wastewater for irrigation of crops is attractive because it removes nutrients from the Clark Fork River system and potentially utilizes those nutrients for production of salable crops. Nutrients are causing eutrophication problems in the river system and their removal would be beneficial. There are, however, significant costs involved in constructing an irrigation system and a number of regulatory requirements that must be met in order to implement a system. The Water Quality Bureau of the Montana Department of Health & Environment Sciences will place a number of restrictions on the transport and disposal of the wastewater. There are restrictions on the types of crops that can be grown and on the ultimate use of those crops plus there are requirements for site access control, buffer zones and groundwater monitoring.

The least expensive alternative is to simply deliver the water to the Flynn/Lowney ditch for ultimate disposal through the existing irrigation systems of the Hellgate Valley Irrigation Co. The president of this irrigation company, however, has indicated that the company probably would not be interested in taking the water. Restrictions on crops and groundwater monitoring requirements may discourage existing irrigation companies from taking the effluent plus these companies are particularly concerned about the increased potential ditch blockage problems caused by aquatic plants that may grow more readily in the nutrient rich wastewater.

The actual cost of an irrigation system will depend on a number of factors and decisions that must be made by the City of Missoula. This report provides only a preliminary screening of potential irrigation sites and typical costs for constructing an irrigation system to serve those general areas. If the City is interested in pursuing the irrigation option further, a basic design flow rate must be selected and the process must be started to determine the number and location of landowners interested in receiving the water and the conditions under which they will accept the water. At this time the City will be able to determine if they will have to participate in the purchase and operation of various types of field irrigation equipment. The City will also be able to determine if there is a market for the water or if they will have to pay landowners to accept the water. Once specific sites are located, the sites can be examined for specific environmental information required by the Water Quality Bureau and the Water Quality Bureau can establish specific operational and monitoring requirements for these sites. Cost estimates can also be revised to reflect the delivery system required to actually serve the sites.

RAPID INFILTRATION

A rapid infiltration system could be constructed that would take the wastewater on a year around basis. Although most of the contaminants would be removed as the water percolated through the soil, the system may still have difficulty in meeting requirements and definitions relative to non-degradation of ground water. The project would be difficult to implement because of the large amount of land that must be purchased and because of the detailed engineering studies that would probably be required to show that the system probably would not adversely affect ground water quality or impact domestic water supply wells in the area. This alternative is substantially more expensive than an irrigation system but would potentially provide year around phosphorous removal instead of just the 120 day irrigation season.

APPENDIX

TABLE 2

OWNERSHIP OF POTENTIAL IRRIGATION SITES[1]

A.	Gaspard W. Deschamps	3207 Park	549-0545
B.	Missoula County (Airport)		728-4381
C.	Charles M. and Nancy A. Deschamps	8150 Mullan Road	549-3196
D.	Margueritte L. Miller	Kona Ranch	543-6124
E.	Earl M. Pruyn (and Warren Swartz)	4527 Rio Vista Drive	251-4000
F.	George Elmer and Mary Flynn, et. al.	2100 Flynn Lane	549-6252
G.	James M. and Norma H. Bauer	2244 Wyoming	543-3618 (Shop 543-5504)
H.	George E. Flynn (Elmer) Patricia and Clarence Sinclair Living Trust Frances McQuade	2100 Flynn Lane	549-6252
I.	Dougherty Farm James Dougherty	3675 Flynn Lane	728-4628
J.	Arthur R. Alice M. M. Kintner and Robert L. & Della Deschamps		
K.	Emmett H. and Kathryn R. Flynn	5000 Mullan Road	549-0552
L.	Kathleen McKinnon	2315 Flynn Lane	549-6829
M.	Royal A. McConkey	6400 Mullan Road	549-3859
N.	Alice McConkey		
O.	Milo R. & Jean Janecek		251-2901
P.	William E., Jr. and Sandra F. Mytty	Lolo Creek Rd. Lolo, MT	273-2522
R.	Hugh W. Frame	10525 Grant Ck. Rd.	549-7762
S.	Harvey & Mitzie M. Clouse	4405 Mullan Rd.	549-7389

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[1] Names from maps in the Missoula County Appraisal Office; addresses and phone numbers from telephone book.

ESTIMATE 1-A

IRRIGATION DELIVERY SYSTEM
3 MGD OPTION

Description	Quantity	Unit	Unit Price	Price
DELIVERY PIPING				
16" DI Pipe	4,900	L.F.	41.00	200,900.00
14" DI Pipe	5,300	L.F.	37.00	196,100.00
12" PVC Pipe	1,320	L.F.	31.00	40,920.00
8" PVC Pipe	8,500	L.F.	19.00	161,500.00
6" PVC Pipe	3,300	L.F.	17.00	56,100.00
VALVES				
16" B.F. Valves	2	Ea.	2,100.00	4,200.00
14" B.F. Valves	3	Ea.	1,700.00	5,100.00
12" Gate Valves	1	Ea.	1,200.00	1,200.00
8" Gate Valves	4	Ea.	550.00	2,200.00
6" Gate Valves	10	Ea.	500.00	5,000.00
FITTINGS	15,000	Lbs.	2.50	37,500.00
HIGHWAY CROSSING	1	EA.	10,000.00	10,000.00
GRAVEL ROAD CROSSING	2	Ea.	400.00	800.00
DITCH & STREAM CROSSING	3	Ea.	500.00	1,500.00
FIELD AIR/VAC STATIONS	2	Ea.	4,000.00	8,000.00
IRRIGATION CONNECTIONS	16	Ea.	3,000.00	48,000.00
SIGNS	60	Ea.	50.00	3,000.00
OBSERVATION WELLS	5	Ea.	2,500.00	12,500.00
PUMP STATION		L.S.		505,000.00
PLANT YARD PIPING		L.S.		53,500.00
Subtotal				1,353,020.00
Contingency				135,000.00
Legal, Engineering, & Administrative				297,000.00
Subtotal				432,000.00
Total Probable Cost				1,785,020.00

ESTIMATE 1-B

SPRAY IRRIGATION DISTRIBUTION SYSTEMS
3 MGD OPTION

Description	Quantity	Unit	Unit Price	Price
Center Pivot Connections	11	Ea.	4,000.00	44,000.00
Wheel Line Connections	33	Ea.	500.00	16,500.00
Center Pivot Electrical	11	Ea.	6,000.00	66,000.00
Center Pivots-660 Ft.	3	Ea.	24,600.00	73,800.00
Wheel Lines-660 Ft.	3	Ea.	5,600.00	16,800.00
Subtotal				217,100.00
Contingency				11,000.00
Legal, Engineering, & Administrative				27,400.00
Subtotal				38,400.00
Total Probable Cost				255,500.00

ESTIMATE 1-C

DELIVERY SYSTEM OPERATION & MAINTENANCE COST
3 MGD OPTION

Description	Quantity	Unit	Unit Price	Price
Labor	220	Hrs.	20.00	4,400.00
Electricity	120	Days	170.00	20,400.00
Vehicle Use	500	Miles	0.35	175.00
Testing		L.S.		4,000.00
Equip. Reserve		L.S.		3,000.00
Total Probable Cost				31,975.00

Present Worth of Operating & Maintenance Costs = $313,930
(@ 8% for 20 years)

ESTIMATE 1-D

PIVOT IRRIGATION SYSTEM OPERATION & MAINTENANCE COST
3 MGD OPTION

Description	Quantity	Unit	Unit Price	Price
Labor	580	Hrs.	20.00	11,600.00
Fuel	150	Gals.	1.50	225.00
Vehicle Use	1000	Miles	0.35	350.00
Equipment Reserve		L.S.		3,000.00
Total Probable Cost				15,175.00

Present Worth of Operating & Maintenance Costs = $149,000
(@ 8% for 20 Years)

ESTIMATE 2-A

IRRIGATION DELIVERY SYSTEM
6 MGD OPTION

Description	Quantity	Unit	Unit Price	Price
DELIVERY PIPING				
24" DI Pipe	5300	L.F.	60.00	318,000.00
20" DI Pipe	1980	L.F.	54.00	106,920.00
18" DI Pipe	1980	L.F.	46.00	91,080.00
16" DI Pipe	2,640	L.F.	41.00	108,240.00
14" DI Pipe	4,620	L.F.	37.00	170,940.00
12" PVC Pipe	4,640	L.F.	31.00	143,840.00
8" PVC Pipe	6,420	L.F.	19.00	121,980.00
6" PVC Pipe	3,300	L.F.	17.00	56,100.00
VALVES				
24" B.F. Valves	2	Ea.	4,400.00	8,800.00
18" B.F. Valves	1	Ea.	2,600.00	2,600.00
16" B.F. Valves	1	Ea.	2,100.00	2,100.00
14" B.F. Valves	2	Ea.	1,700.00	3,400.00
12" Gate Valves	2	Ea.	1,200.00	2,400.00
8" Gate Valves	21	Ea.	550.00	11,550.00
6" Gate Valves	4	Ea.	500.00	2,000.00
FITTINGS	19,000	Lbs.	2.50	47,500.00
HIGHWAY CROSSING	1	EA.	10,000.00	10,000.00
GRAVEL ROAD CROSSING	2	Ea.	400.00	800.00
DITCH & STREAM CROSSING	6	Ea.	500.00	3,000.00
FIELD AIR/VAC STATIONS	3	Ea.	4,000.00	12,000.00
IRRIGATION CONNECTIONS	28	Ea.	3,000.00	84,000.00
SIGNS	140	Ea.	50.00	7,000.00
OBSERVATION WELLS	12	Ea.	2,500.00	30,000.00
PUMP STATION		L.S.		560,000.00
PLANT YARD PIPING		L.S.		59,600.00
Subtotal				1,963,850.00
Contingency				196,000.00
Legal, Engineering, & Administrative				432,000.00
Subtotal				628,000.00
Total Probable Cost				2,591,850.00

ESTIMATE 2-B

SPRAY IRRIGATION DISTRIBUTION SYSTEMS
6 MGD OPTION

Description	Quantity	Unit	Unit Price	Price
Center Pivot Connections	22	Ea.	4,000.00	88,000.00
Wheel Line Connections	53	Ea.	500.00	26,500.00
Center Pivot Electrical	22	Ea.	6,000.00	132,000.00
Center Pivots-660 Ft.	4	Ea.	24,600.00	98,400.00
Wheel Lines-660 Ft.	4	Ea.	5,600.00	22,400.00
Towing Equipment		L.S.		40,000.00
Subtotal				407,300.00
Contingency				20,400.00
Legal, Engineering, & Administrative				51,300.00
Subtotal				71,700.00
Total Probable Cost				479,000.00

ESTIMATE 2-C

DELIVERY SYSTEM OPERATION & MAINTENANCE COST
6 MGD OPTION

Description	Quantity	Unit	Unit Price	Price
Labor	220	Hrs.	20.00	4,400.00
Electricity	120	Days	360.00	43,200.00
Vehicle Use	500	Miles	0.35	175.00
Testing		L.S.		6,000.00
Equip. Reserve		L.S.		3,700.00
Total Probable Cost				57,475.00

Present Worth of Operating & Maintenance Costs = $564,290
(@ 8% for 20 Years)

ESTIMATE 2-D

PIVOT IRRIGATION SYSTEM OPERATION & MAINTENANCE COST
6 MGD OPTION

Description	Quantity	Unit	Unit Price	Price
Labor	570	Hrs.	20.00	11,400.00
Fuel	350	Gals.	1.50	525.00
Vehicle Use	2000	Miles	0.35	700.00
Equipment Reserve		L.S.		4,600.00
Total Probable Cost				17,225.00

Present Worth of Operating & Maintenance Costs = $169,110
(@ 8% for 20 Years)

ESTIMATE 3-A

IRRIGATION DELIVERY SYSTEM
9 MGD OPTION

Description	Quantity	Unit	Unit Price	Price
DELIVERY PIPING				
24" DI Pipe	14,600	L.F.	60.00	876,000.00
18" DI Pipe	6,700	L.F.	46.00	308,200.00
16" DI Pipe	700	L.F.	41.00	28,700.00
14" DI Pipe	4,620	L.F.	37.00	170,940.00
12" PVC Pipe	4,700	L.F.	31.00	145,700.00
8" PVC Pipe	18,300	L.F.	19.00	347,700.00
6" PVC Pipe	6,600	L.F.	17.00	112,200.00
VALVES				
24" B.F. Valves	3	Ea.	4,400.00	13,200.00
18" B.F. Valves	3	Ea.	2,600.00	7,800.00
16" B.F. Valves	1	Ea.	2,100.00	2,100.00
14" B.F. Valves	2	Ea.	1,700.00	3,400.00
12" Gate Valves	2	Ea.	1,200.00	2,400.00
8" Gate Valves	37	Ea.	550.00	20,350.00
6" Gate Valves	16	Ea.	500.00	8,000.00
FITTINGS	32,000	Lbs.	2.50	80,000.00
HIGHWAY CROSSING	1	EA.	10,000.00	10,000.00
GRAVEL ROAD CROSSING	4	Ea.	400.00	1,600.00
DITCH & STREAM CROSSING	7	Ea.	500.00	3,500.00
FIELD AIR/VAC STATIONS	6	Ea.	4,000.00	24,000.00
IRRIGATION CONNECTIONS	40	Ea.	3,000.00	120,000.00
SIGNS	200	Ea.	50.00	10,000.00
OBSERVATION WELLS	16	Ea.	2,500.00	40,000.00
PUMP STATION		L.S.		600,000.00
PLANT YARD PIPING		L.S.		59,600.00
STORAGE TANK		L.S.		287,000.00
Subtotal				3,282,390.00
Contingency				328,000.00
Legal, Engineering, & Administrative				722,000.00
Subtotal				1,050,000.00
Total Probable Cost				4,332,390.00

ESTIMATE 3-B

SPRAY IRRIGATION DISTRIBUTION SYSTEMS
9 MGD OPTION

Description	Quantity	Unit	Unit Price	Price
Center Pivot Connections				
6" Connections	14	Ea.	4,000.00	56,000.00
8" Connections	30	Ea.	4,000.00	120,000.00
Wheel Line Connections	90	Ea.	500.00	45,000.00
Center Pivot Electrical	44	Ea.	6,000.00	264,000.00
Center Pivots				
660 Ft. Length	20	Ea.	24,600.00	492,000.00
1000 Ft. Length	1	Ea.	36,500.00	36,500.00
1300 Ft. Length	2	Ea.	47,000.00	94,000.00
Wheel Lines-660 Ft.	14	Ea.	5,600.00	78,400.00
Pivot Towing Equipment		L.S.	40,000.00	40,000.00
Wheel Line Booster Pumps	4	Ea.	20,000.00	80,000.00
Subtotal				1,305,900.00
Contingency				65,000.00
Legal, Engineering, & Administrative				164,000.00
Subtotal				229,000.00
Total Probable Cost				1,534,900.00

ESTIMATE 3-C

DELIVERY SYSTEM OPERATION & MAINTENANCE COST
9 MGD OPTION

Description	Quantity	Unit	Unit Price	Price
Labor	220	Hrs.	20.00	4,400.00
Electricity	120	Days	492.00	59,040.00
Vehicle Use	500	Miles	0.35	175.00
Testing		L.S.		8,000.00
Equip. Reserve		L.S.		4,500.00
Total Probable Cost				76,115.00

Present Worth of Operation & Maintenance Costs = $747,300
(@ 8% for 20 Years)

ESTIMATE 3-D

PIVOT IRRIGATION SYSTEM OPERATION & MAINTENANCE COST
9 MGD OPTION

Description	Quantity	Unit	Unit Price	Price
Labor	1120	Hrs.	20.00	22,400.00
Fuel	500	Gals.	1.50	750.00
Equipment Reserve		L.S.		16,000.00
Vehicle Use	3000	Miles	0.35	1,050.00
Total Probable Cost				40,200.00

Present Worth of Operating & Maintenance Costs - $394,700
(@ 8% for 20 Years)

ESTIMATE 3-E

IRRIGATION DELIVERY SYSTEM
9 MGD OPTIONAL SERVICE AREA

Description	Quantity	Unit	Unit Price	Price
DELIVERY PIPING				
16" DI Pipe	5,400	L.F.	41.00	221,400.00
12" PVC Pipe	9,100	L.F.	31.00	282,100.00
10" PVC Pipe	1,900	L.F.	23.00	43,700.00
8" PVC Pipe	4,000	L.F.	19.00	76,000.00
6" PVC Pipe	5,300	L.F.	17.00	90,100.00
VALVES				
16" B.F. Valves	1	Ea.	2,100.00	2,100.00
12" Gate Valves	2	Ea.	1,200.00	2,400.00
10" Gate Valves	1	Ea.	900.00	900.00
8" Gate Valves	21	Ea.	550.00	11,550.00
6" Gate Valves	4	Ea.	500.00	2,000.00
FITTINGS	14,000	Lbs.	2.50	35,000.00
HIGHWAY CROSSING	1	EA.	10,000.00	10,000.00
GRAVEL ROAD CROSSING	2	Ea.	400.00	800.00
RAILROAD OPEN CUT	1	Ea.	200.00	200.00
DITCH & STREAM CROSSING	2	Ea.	500.00	1,000.00
FIELD AIR/VAC STATIONS	2	Ea.	4,000.00	8,000.00
Center Pivot Connections				
6" Connections	3	Ea.	4,000.00	12,000.00
8" Connections	2	Ea.	4,000.00	8,000.00
Wheel Line Connections	60	Ea.	500.00	30,000.00
Center Pivot Electrical	5	Ea.	6,000.00	30,000.00
Center Pivots				
660 Ft. Length	3	Ea.	24,600.00	73,800.00
1000 Ft. Length	1	Ea.	36,500.00	36,500.00
1300 Ft. Length	1	Ea.	47,000.00	47,000.00
Wheel Lines-660 Ft.	5	Ea.	5,600.00	28,000.00
Pivot Towing Equipment		L.S.	40,000.00	40,000.00
Wheel Line Booster Pumps	4	Ea.	24,000.00	96,000.00
SIGNS	50	Ea.	50.00	2,500.00
OBSERVATION WELLS	10	Ea.	2,500.00	25,000.00
PLANT YARD PIPING		L.S.		59,600.00
Subtotal				1,275,650.00
Contingency				123,000.00
Legal, Engineering, & Administrative				163,000.00
Subtotal				286,000.00
Total Probable Cost				1,561,650.00

ESTIMATE 4-A

IRRIGATION DELIVERY SYSTEM
HELLGATE VALLEY IRRIGATION CO. OPTION

Description	Quantity	Unit	Unit Price	Price
DELIVERY PIPING				
24" DI Pipe	2,300	L.F.	60.00	138,000.00
VALVES				
24" B.F. Valves	1	Ea.	4,400.00	4,400.00
FITTINGS	4,100	Lbs.	2.50	10,250.00
SIGNS	2	Ea.	50.00	100.00
PUMP STATION		L.S.		560,000.00
PLANT YARD PIPING		L.S.		59,600.00
Subtotal				772,350.00
Contingency				77,000.00
Legal, Engineering, & Administrative				169,900.00
Subtotal				246,900.00
Total Probable Cost				1,019,250.00

ESTIMATE 4-B

DELIVERY SYSTEM OPERATION & MAINTENANCE COST
HELLGATE VALLEY IRRIGATION CO. OPTION

Description	Quantity	Unit	Unit Price	Price
Labor	220	Hrs.	20.00	4,400.00
Electricity	120	Days	130.00	15,600.00
Vehicle Use	500	Miles	0.35	175.00
Equip. Reserve		L.S.		3,700.00
Total Probable Cost				23,875.00

Present Worth of Operating and Maintenance Costs = $234,400
(@ 8% for 20 Years)

RAPID INFILTRATION

ITEM NO.	DESCRIPTION	EST. QUANTITY/UNIT		UNIT PRICE	AMOUNT
1.	Yard Piping		Lump Sum		$ 59,000.00
2.	Pump Building				570,000.00
3.	24" D.I. Pipe	15,660	L.F.	60.00	939,600.00
4.	18" D.I. Pipe	8,700	L.F.	46.00	400,200.00
5.	16" D.I. Pipe	7,560	L.F.	41.00	309,960.00
6.	Fittings	60,000	LBS.	2.50	150,000.00
7.	Inlet Installation	81	EA.	10,700.00	866,700.00
8.	Overflow Piping	81	EA.	300.00	24,300.00
9.	Pond Alarms	34	EA.	300.00	10,200.00
10.	Underground Electrical for Valve Control	31,000	L.F.	3.50	108,500.00
11.	Underground Control Cable to Plant	14,000	L.F.	1.50	21,000.00
12.	Control System		Lump Sum		70,000.00
13.	Electrical Service to Control Bldg.		Lump Sum		16,000.00
14.	Pond Excavation	325,000	C.Y.	3.30	1,072,500.00
15.	Control and Maintenance Bldg.		Lump Sum		96,000.00
16.	Distribution System Access Roads	26,100	L.F.	15.00	391,500.00
17.	Main Access Road	4,600	L.F.	33.00	151,800.00
18.	Fencing	8,500	L.F.	2.00	17,000.00
19.	Signing	50	EA.	50.00	2,500.00
20.	Seeding	300	AC.	1,600.00	480,000.00

OPERATION AND MAINTENANCE COSTS
RAPID INFILTRATION

ITEM NO.	DESCRIPTION	EST. QUANTITY/UNIT	UNIT PRICE	AMOUNT
	Labor	1,360 HRS.	20.00	$ 27,200.00
	Electricity	120 DAYS	153.00	18,360.00
	Capital Equipment Replacement	Lump Sum		11,000.00
	Testing	Lump Sum		11,000.00
	Vehicle Use	4,000 MI.	0.25	1,000.00
	Fuel for Tractor	1,100 GAL.	1.00	1,100.00
	TOTAL:			$ 69,660.00

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MISSOULA LAND APPLICATION STUDY

PRELIMINARY REPORT I

Prepared For:
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By:
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January 10, 1990

INTRODUCTION

The most widely accepted definition for wetlands accepted by wetlands scientists in the United States today was adopted by the U.S. Fish and Wildlife Service in 1979 [Mitsch and Gosselink 1986]. As promulgated by the U.S. Fish and Wildlife Service, the definition is " Wetlands are lands transitional between terrestrial and aquatic systems where the water table is usually at or near the surface or the land is covered by shallow water. Wetlands must have one or more of the following three attributes: (1) at least periodically, the land supports predominantly hydrophytes, (2) the substrate is predominantly undrained hydric soil, and (3) the substrate is nonsoil and is saturated with water or covered by shallow water at some time during the growing season each year." For legal purposes, the prevalent definition is the definition adopted by the U.S. Army Corps of Engineers "... those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas. (33 CFR323.2(c); 1984)." In 1981, additional criteria of: frequency of inundation, soils type, and vegetation were added by the U.S. District Court in Louisiana.

A more general definition defines wetlands as areas flooded or saturated by surface water or groundwater often and long enough to support those types of vegetation and aquatic life that require or are specially adapted for saturated soil conditions [Hammer 1989].

LOCATION

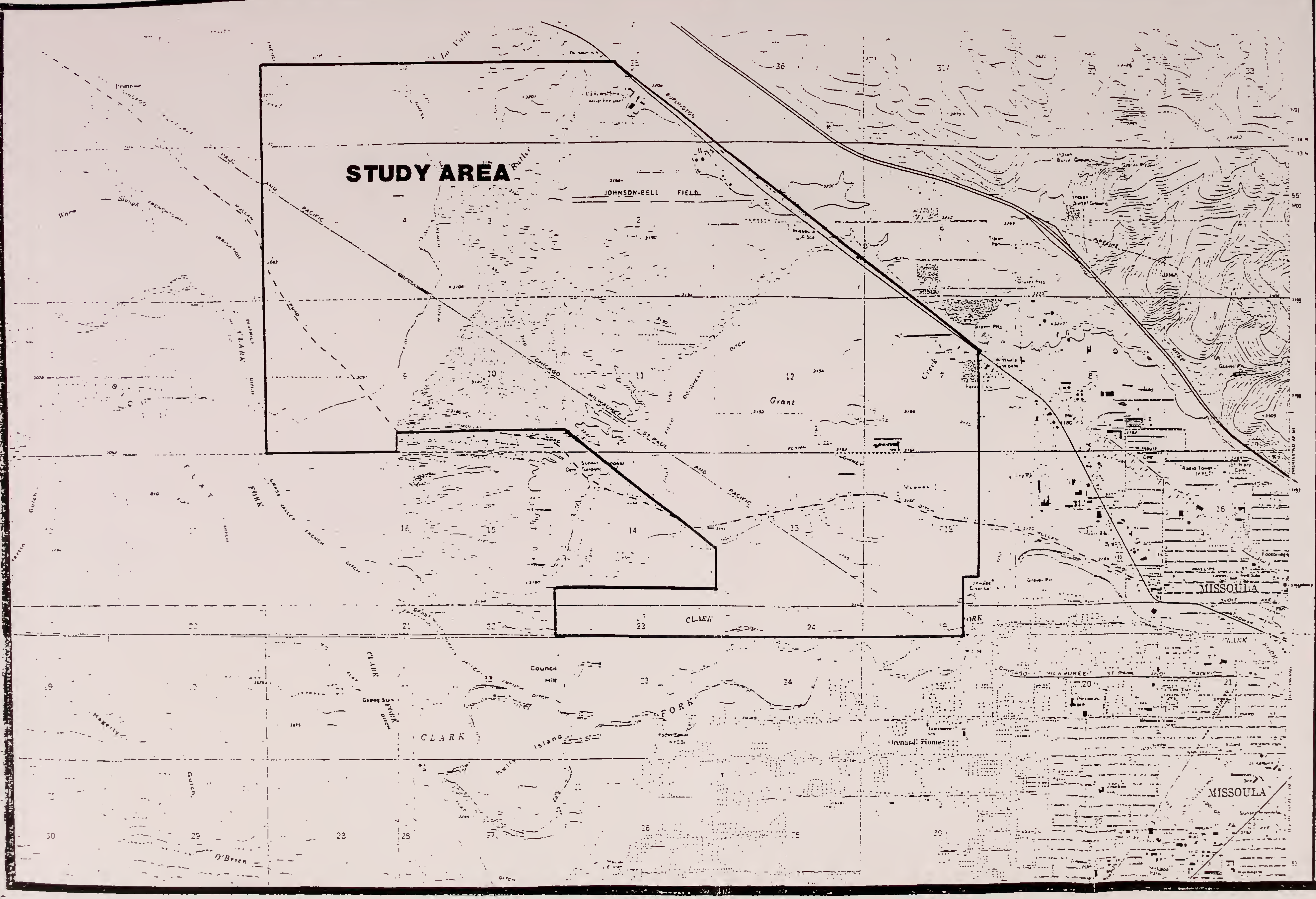
The study area defined on Figure 1, is located approximately 1.25 miles west of Missoula, Montana, in Missoula County. The study area consists of approximately 12 mi.^{2} generally bordered on the south and west by the Clark Fork River, Reserve Drive on the east and U.S. Highway 10 on the north. Specifically, the study area consists of sections 1,2,3,4,9,10.11,12, 13 and parts of sections 14, 23, and 24 of T13N, R20W. Parts of sections 33, 34, and 35 of T14N, R20W and sections 7, 18, and 19 of T13N, R19W are also included.

HYDRAULIC CONDITIONS

The design flow volume is 9 million gallons per day (mgd). The principle purpose of utilizing a land treatment alternative for wastewater renovation by the City of Missoula is to control the amount of phosphorus reaching the Clark Fork River annually through the discharge of treated wastewater into the river. The treatment system may be operated for all or part of the year.

WETLAND FUNCTION

Wetlands provide effective treatment of many types of water pollution. They can effectively remove or convert large quantities of pollutants including organic matter, suspended solids, metals and excess nutrients. This reduction is accomplished by diverse treatment mechanisms: sedimentation, filtration, chemical precipitation and adsorption, microbial interactions, and uptake by vegetation. At least one study of virus removal by treatment of wastewater in a con-



PROJECT: MISSOULA LAND APPLICATION STUDY - PRELIMINARY REPORT

DRAWING: VICICITY MAP. FIGURE 1.

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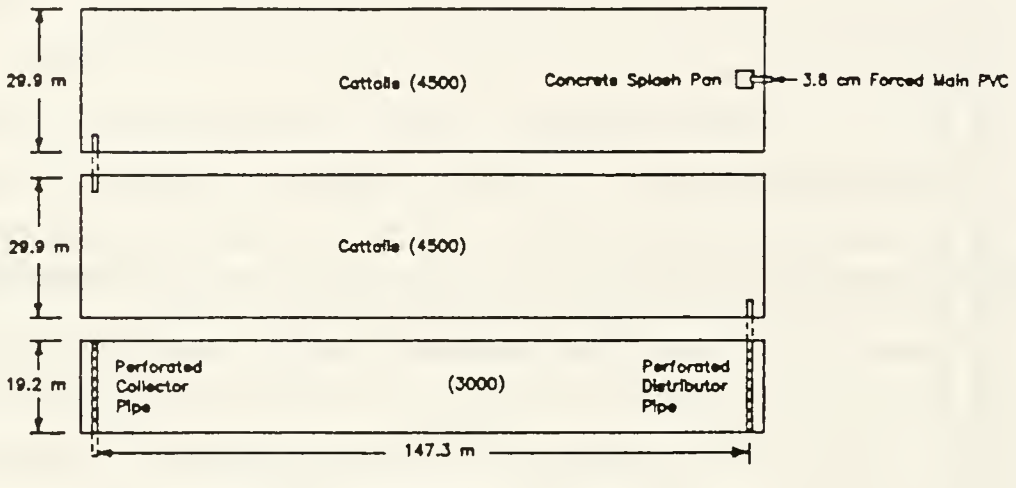
structed wetland, found virus removal of 99% with the greatest removal of non-indigenous phages [Gersberg, Lyon, Brenner and Elkins 1987]. Wetlands are considered in two forms in this report, "natural", including bogs and marshes, and "constructed" wetlands. The latter are defined as "a designed and man-made complex of saturated substrates, emergent and submergent vegetation, animal life, and water that simulates natural wetlands for human use and benefits" [Hammer 1989]. Use of natural wetlands for tertiary treatment of wastewater, particularly for the removal of phosphorus, is limited by the capacity of sediments for phosphorus storage [Brinson, Bradshaw and Kane 1984]. Most constructed wetlands for wastewater treatment emulate marshes. The most successful constructed wetlands, which can be designed for enhanced phosphorus removal, utilize herbaceous emergent and occasionally submergent plants.

Figure 2 illustrates a submerged bed constructed wetland. Two common plants in western Montana that have been utilized for wastewater treatment are cattails (Typha latifolia) and duckweed (Lemna minor).

MINIMUM REQUIRED LAND AREA

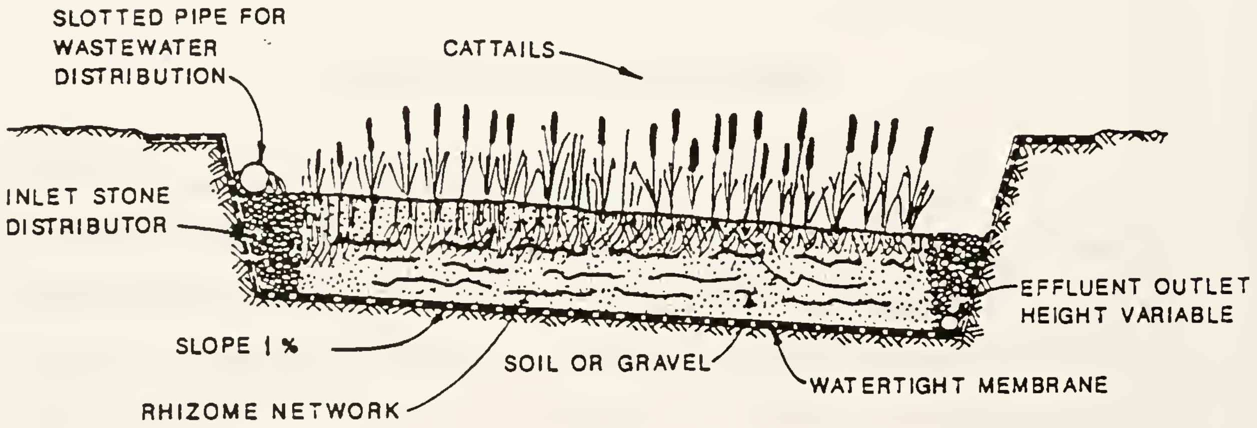
Design of a constructed wetland for treatment of municipal wastewater requires analysis of a number of site specific characteristics. A constructed wetland designed for surface flow consists of basins or channels, soil or another suitable medium to support emergent vegetation, and relatively shallow water flowing through the unit. Typical construction types include the conventional wetland with a free water surface and the vegetated submerged bed. Channels are typically long and narrow with length-to-width rations of 10:1, ensuring approximate plug-flow conditions in surface flowing systems. In submerged bed systems, the length-to-width ratios may be less than 3:1. In surface flow

CONSTRUCTED WETLANDS FOR WASTEWATER TREATMENT



PLAN VIEW

Typical cross section



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PROJECT: MISSOULA LAND APPLICATION STUDY-
PRELIMINARY STUDY.

DRAWING: CONSTRUCTED WETLAND. FIGURE 2.

systems, longitudinal gradients range from 0 - 1% with lateral gradient of 0%. In submerged bed systems with coarse gravel for the substrate, longitudinal slopes in excess of 2% are acceptable with the outlet structure controlling the flow rate.

Area estimates for planning purposes are based on past performance of free-water-surface and vegetated submerged bed systems. In general, the former requires more space but less construction activity while the latter achieves greater phosphorus removal. Basic design criteria are:

- Detention time - 7 days
- Flow depth - 0.75 - 1.0 ft.
- Organic loading - 20 lbs./acre/day

Based on a typical hydraulic loading rate of 23 acre/mgd [Hammer 1989], the minimum free-water-surface wetland required to treat 9 mgd is 366 acres. These would be constructed as a series of smaller cells. Based on additional results of installed systems [Reed, Middlebrooks and Crites 1988], the required land area could be 223 acres. Phosphorus removal in free-water-surface wetlands is substantially less than in submerged bed designs. Submerged bed designs however, require less area for 9 mgd; approximately 210 acres. To achieve phosphorus levels of approximately one in the treated effluent, a calcareous gravel or pretreatment of the influent would be required.

EXISTING WETLANDS

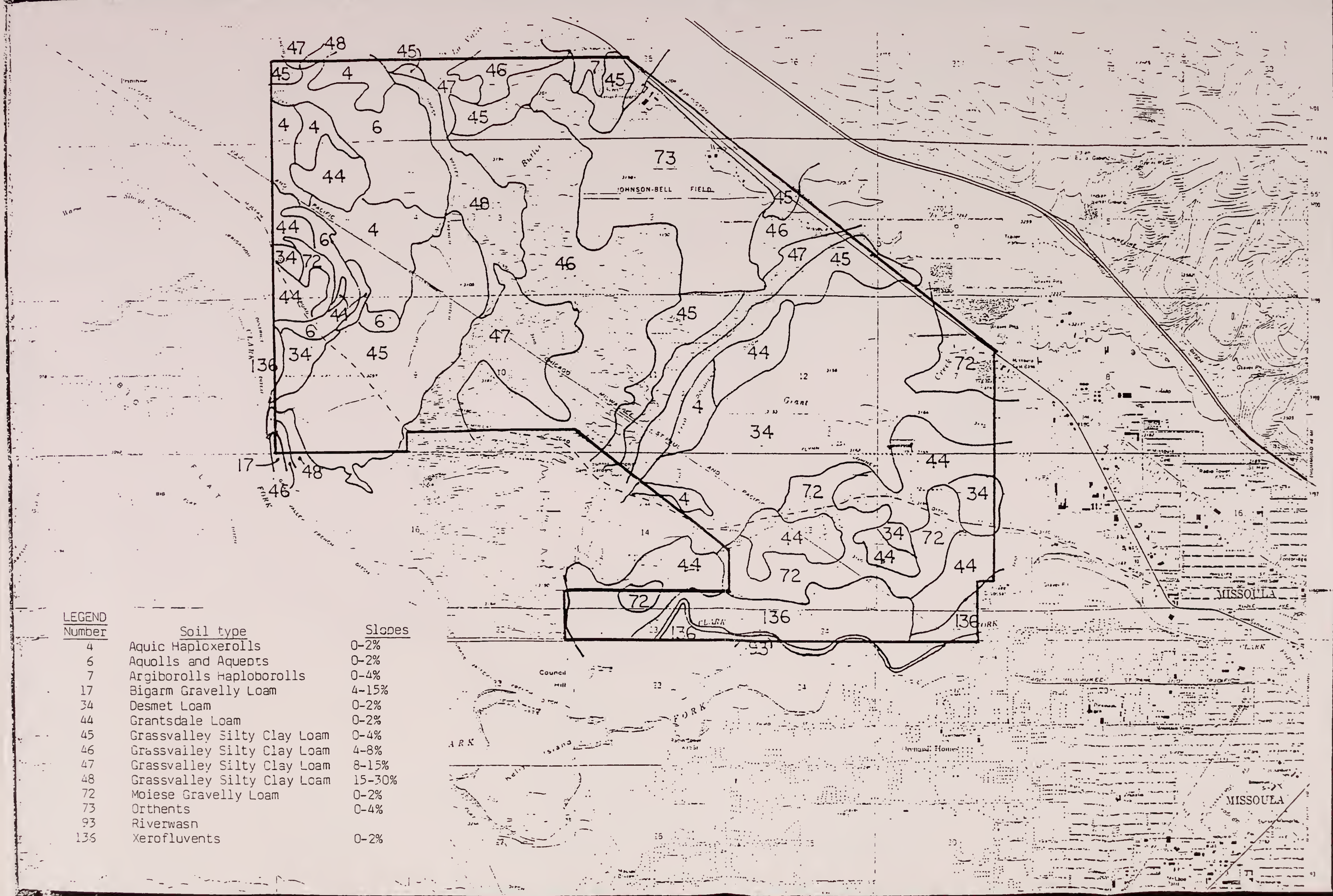
Within the study area, there are very few "wetlands". Existing wetlands are limited to zones bordering the Clark Fork River and along major drainages such as Butler and Grant Creeks. Due to limited size and proximity to the designated floodplain, existing natural wetlands are unsuited for treatment of wastewater.

POTENTIAL APPLICATION AREAS

Application areas exist in two types of terrain (see Figure 3). The first is the irrigated agricultural land in the Grant Creek drainage. This land is nearly flat and in blocks large enough to accommodate the 300-400 acre areas required for installation of a submerged bed wetland. Use of this acreage for wetland treatment would preclude its use for any other purpose thereby removing productive agricultural land from production. Alternatively, the silty clay loam soils southwest of the airport provide an opportunity for long narrow terraces parallel to the topographic contours consisting of submerged bed wetlands that could be loaded from the top with the wastewater cascading downhill through multiple beds and eventually into the Grass Valley French Ditch. Hence, the treated water could then seasonally be used for agricultural irrigation.

SUMMARY

Wetlands provide an economical and effective means of treating wastewater throughout the year. Existing natural wetlands in the study area are inadequate for treating the design flow of 9 mgd from the Missoula wastewater treatment plant. Constructed wetlands provide the best wetland alternative, especially the submerged bed variety. The submerged bed wetland is recommended due to its lessor size than the free-water-surface wetland and its enhanced ability to remove phosphorus from the influent. The minimum required area for wetlands treatment of the design flow would be approximately 210 acres.



LEGEND

Number	Soil type	Slopes
4	Aquic Haploxerolls	0-2%
6	Aquolls and Aquepts	0-2%
7	Argiborolls Haploborolls	0-4%
17	Bigarm Gravelly Loam	4-15%
34	Desmet Loam	0-2%
44	Grantsdale Loam	0-2%
45	Grassvalley Silty Clay Loam	0-4%
46	Grassvalley Silty Clay Loam	4-8%
47	Grassvalley Silty Clay Loam	8-15%
48	Grassvalley Silty Clay Loam	15-30%
72	Moiese Gravelly Loam	0-2%
73	Orthents	0-4%
93	Riverwash	
136	Xerofluvents	0-2%

PROJECT: MISSOULA LAND APPLICATION STUDY – PRELIMINARY REPORT.

DRAWING: SOILS MAP. FIGURE 3.

STRATA & ASSOCIATES
CONSULTING HYDROGEOLOGY

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MISSOULA LAND APPLICATION STUDY

PHASE I: PRELIMINARY EVALUATION OF IRRIGATION AND CROP ALTERNATIVES

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PREFACE

The author of this report does not assume responsibility for the accuracy of effluent water chemistry data, or soils data from the Soil Conservation Service (USDA). These data were used to present several possible management alternatives for the disposal of final sewage effluent from the Missoula Wastewater Treatment Plant. It is expected that further study during Phase II of this project would be necessary to develop final recommendations.

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BRIEF DESCRIPTION OF SOIL TYPES WITHIN STUDY AREA (Table 1)

1. *De Smet loam* (map unit 34; 18.7 % of study area)

Deep well drained soils formed in alluvium. Slopes range from 0-2%. Surface textures are loams. Available water holding capacity (AWC) varies from 0.13 to 0.18 inches water per inch soil, which represents a cumulative AWC of 9 to 10 inches in a 5 foot soil profile. Soil erodibility will be slight on slopes less than 0.5 % and moderate on slopes between 0.5 and 2.0%. Permeability ranges from 0.6-2.0 in/hr in all horizons down to 5 feet. The De Smet series can handle "maximum sprinkler application rates" ranging from 1 in/hr at high net applications (e.g. 5.0 inches) to 5.4 in/hr at low net applications (e.g. <1 inch).

The De Smet loam is extremely suitable for irrigation and tillage operations and represents prime farmland when irrigated. Water tables are normally greater than 6 feet and should not present a problem for applying maximum irrigation rates.

2. *Grassvalley silty clay loam*

map unit	slope	percent of study
45	0-4	14.8
46	4-8	14.8
47	8-15	6.5
48	15-30	3.6

Deep, well drained soils formed from lacustrine deposits. Slopes range from 0 to 30%; slope variability is used to separate the Grassvalley series into 4 mapping units. Surface textures are silty clay loams with clay content increasing with depth, where textures below the Ap horizon are often silty clays or clays. Available water holding capacity (AWC) ranges from 0.14-0.2 in/in down to 5 feet representing a cumulative AWC of 8.6-10 inches.

The most important difference among the Grassvalley series and De Smet and Grantsdale series is the lower permeability in the Grassvalley series resulting from much higher clay content. Permeability in the Grassvalley series is 0.06-0.2 in/hr in the Ap horizon (0-9 inches) and <0.06 in/hr from approximately 10-60 inches. Consequently, the Grassvalley soils have lower maximum sprinkler application rates. For example, at a net application of 5 inches, the maximum sprinkler application rate is 0.25-0.26 in/hr and at a net application of 1 inch, the rate is 0.7-1.7 in/hr depending on the percent slope.

Soil erodibility will be slight on slopes less than 4%, moderate on slopes ranging from 0.4-2.0% and severe on slopes greater than 2.0%. Although the Grassvalley soils are not considered prime farmland, they can be irrigated and cropped with correct management practices.

3. *Grantsdale loam* (map unit 44; 11.9% of study area)

Deep, well drained soils formed in alluvium. Slopes range from 0-2% Surface textures are loams, becoming gravelly loams in substratum. Available water holding capacity (AWC) ranges from 0.13-0.20 in/in down to 32 inches after which the AWC drops to 0.03-0.04 in/in due to the gravelly substratum. Cumulative AWC down to 5 feet ranges from 5.4-7.0 inches.

Soil erodibility is slight on slopes less than 0.5% and moderate on slopes ranging from 0.5-2.0%. Permeability is excellent ranging from 0.6-2.0 inches/hr down to 32 inches, and 6.0-2.0 inches/her from 32-60 inches. Consequently, the Grantsdale series can accept high "maximum sprinkler irrigation rates" ranging from 1 in/hr at high net applications (e.g. 5 in) to 5.4 in/hr at low net applications (e.g. 1 in). These soils are very suitable for tillage operations and represent prime farm land when irrigated. Water tables are normally greater than 6 feet. This series is very similar to the De Smet series but shallower. The Grantsdale and De Smet series represent some of the best farmland in the study area and most suitable soils for management.

4. *Moiese gravelly loam* (map unit 72; 7.0% of study area)

Deep well drained soils that formed in sandy and gravelly alluvium. Slopes range from 0 to 2%. Surface textures are loams or gravelly loams which continue to depths of

5 feet. Available water holding capacity (AWC) ranges from 0.16-0.18 in/in in the surface horizon (8 inches) but drops to 0.03-0.07 in/in from 10-60 inches. Consequently, the cumulative AWC for a 5 feet profile depth is only 3-4 inches.

Soil erodibility is slight on slopes less than 0.5% and moderate on slopes ranging from 0.5-2.0%. Permeability is high ranging from 0.6-2.0 in/hr at the surface to 2.0-20.0 in/hr at depth. Consequently, the Moiese soils can accept high maximum sprinkler application rates of 1 in/hr for net applications of 5 inches and 5.4 in/hr for net applications of 1 inch. Moiese soils would not be considered prime farmland due to their low AWC, and coarse texture.

MAPPING UNITS WITH NO SOILS INTERPRETATION RECORDS

1. *Orthents* (map unit 73; 6.6 % of study area)

Deep well drained coarse textured soils which occupy disturbed sites on terraces. In the study area, the only location of this mapping unit is the airport.

2. *Aquic Haploxerolls* (map unit 4; 6.5% of study area)

Deep, poorly drained soils formed in alluvium and lacustrine deposits on 0-2% slopes. Textures are loams at the surface, breaking to silt loams, silty clay loams and clays at increasing depths.

Because of their proximity to adjacent streams and rivers in valley bottoms, seasonal water tables are as high as 20 to 40 inches, which makes these soils unsuitable for use in the study.

3. *Aquolls and Aquepts* (map unit 6; 5.7% of study area)

Deep, poorly drained and very poorly drained soils formed from alluvium and lacustrine deposits. These soils are on stream terraces, lacustrine terraces and glacial moraines. Surface textures vary from clay to gravelly sand.

Seasonal water tables range from at or near the surface to 36 inches making these soils unsuitable for effluent application.

4. ***Xerofluvents*** (map unit 136; 3.4% of study area)

Deep, somewhat poorly drained to well drained soils formed in alluvial flood plains with 0-2% slope. Textures are coarse throughout the profile; sandy loams at the surface, breaking to gravelly loamy sands at depth.

Although there is no soil interpretation record for this mapping unit from which to estimate AWC and permeability, these soils are not prime farmland and would be difficult to utilize for irrigation management.

5. ***Argiborolls and Haploborolls*** (map unit 7; 0.4% of study area)

Deep well drained soils formed from tertiary sediments, on 0-60 percent slopes of terraces and foothills. This soil represents such a small percentage of the study area and have such undesirable characteristics for production that they will not be considered further.

Table 1. Soil Types and Percent Distribution in the Approximately 6,850 Acre Study Area.

Soil Series or Description	% Slope	Map Unit	% of Study Area
De Smet Loam	0-2	34	18.7
Grassvalley Silty Clay Loam	0-4	45	14.8
Grassvalley Silty Clay Loam	4-8	46	14.8
Grantsdale Loam	0-2	44	11.9
Moiese Gravelly Loam	0-2	72	7.0
Orthents		73	6.6
Aquic Haploxerolls	0-2	4	6.5
Grassvalley Silty Clay Loam	8-15	47	6.5
Aquolls and Aquepts	0-2	6	5.7
Grassvalley Silty Clay Loam	15-30	48	3.6
Xerofluvents	0-2	136	3.4
Argiborolls and Haploborolls	0-60	7	0.4

CROP AND WATER MANAGEMENT ALTERNATIVES

Crop production alternatives on soils within the study area include alfalfa, grass hay, and grain crops such as winter wheat, spring wheat, barley or oats. Estimates of consumptive use by these crops based on climatic conditions at the weather station located in Missoula, Montana, are listed in Table 2 (Montana Irrigation Guide, USDA-SCS). Additional estimates of consumptive use were obtained using evapotranspiration (ET) data from the Montana State University MAPS mailbox (version 3.1). With the exception of the potential ET calculated from the Penman equation, estimates from the Solar Thermal Unit method, the Thornthwaite method and the Balaney-Criddle method (USDA-SCS) are quite consistent and suggest that consumptive use will range from 23-27 inches annually.

Table 2. Estimates of consumptive use and evapotranspiration at the study area (centered on section 11, 13N, 20W)

	Consumptive Use * (inches)			Evapotranspiration **		
Month	Alfalfa	Grass Hay	Spring Grain	Solar Thermal	Penman	Thornthwaite
Jan-March	-- ***	--	--	0.4	4.3	0.4
April	--	0.8	0.3	1.6	3.5	1.6
May	3.3	3.2	2.7	3.6	5.3	3.1
June	5.6	4.6	6.2	4.6	5.7	4.0
July	7.3	6.2	6.7	7.0	8.1	5.1
August	6.5	5.3	1.2	5.8	7.4	4.7
September	3.3	2.9	--	2.9	4.0	2.8
October	--	0.6	--	1.1	1.8	1.5
Nov.-Dec.	--	--	--	0.1	1.8	0.2
TOTAL	26	24	17	27	42	23

* Balaney-Criddle Method (USDA-SCS)
** MSU MAPS Mail Box Version 3.1
*** No Consumptive Use Is Calculated When There Is No Crop

Consumptive use demand for optimum yields must be met by a combination of irrigation and precipitation. Estimates of irrigation demand which account for both growing season precipitation and non-growing season stored precipitation (split between beginning and end of growing season) are useful for planning sprinkler application amounts for optimum yields (Table 3-5). These net irrigation applications represent minimum values for optimum crop productivity. In a sewage disposal site, it should be possible to exceed these irrigation applications without sacrificing crop productivity and water quality.

Table 3. Estimates of net irrigation required by month to meet consumptive use demands for alfalfa after consideration of effective precipitation (USDA-SCS).

Month	Consumptive Use (inches)	Effective Precipitation*** (inches)	Net Irrigation (inches)
MAY	3.3	0.7 - 1.0**	0.01 - 0.34*
JUNE	5.6	1.0 - 1.5	4.0 - 4.5
JULY	7.3	0.6 - 0.8	6.6 - 6.8
AUGUST	6.5	0.6 - 0.8	5.2 - 5.5
SEPTEMBER	3.3	0.5 - 0.7	0.34 - 0.58
OCTOBER	--	0.01 - 0.02	--------
TOTAL	26	3.4 - 4.8	16.1 - 17.7

* estimated range for normal to dry year
** estimated range for dry to normal year
*** approximately 5 inches of stored soil moisture from precipitation during non growing season months is assumed available to meet consumptive use demand. The 5 inches is split between the demand for May and September.

Table 4. Estimates of net irrigation required by month to meet consumptive use demands for grass hay after consideration of effective precipitation (USDA-SCS).

Month	Consumptive Use (inches)	Effective Precipitation*** (inches)	Net Irrigation (inches)
APRIL	0.8	0.2 - 0.3**	0
MAY	3.2	0.8 - 1.1	0.76 - 1.2*
JUNE	4.6	1.0 - 1.4	3.1 - 3.5
JULY	6.2	0.5 - 0.7	5.4 - 5.6
AUGUST	5.3	0.5 - 0.8	4.4 - 4.6
SEPTEMBER	2.9	0.5 - 0.7	0.3 - 1.1
OCTOBER	0.6	0.2 - 0.3	0
TOTAL	24	3.7 - 5.3	14.5 - 16.0

* estimated range for a normal to dry year

** estimated range for a dry to normal year

*** approximately 4 inches is assumed available from non growing season stored precipitation to meet consumptive use demand.

Table 5. Estimates of net irrigation required by month to meet consumptive use demands for spring grain after consideration of effective precipitation (USDA-SCS).

Month	Consumptive Use (inches)	Effective Precipitation*** (inches)	Net Irrigation (inches)
APRIL	0.3	0.14 - 0.2**	0.0
MAY	2.7	0.8 - 1.1	0.0
JUNE	6.2	1.1 - 1.5	3.9 - 4.8*
JULY	6.7	0.5 - 0.8	4.4 - 4.8
AUGUST	1.2	0.4 - 0.5	0
SEPTEMBER	--	---	0
OCTOBER	--	---	0
TOTAL	17	2.9-4.1	8.3-9.6

* estimated range for a normal to dry year
** estimated range for a dry to normal year
*** approximately 4 inches is assumed available from non growing season stored precipitation to meet consumptive use demand.

It is difficult to estimate from the available data exactly how much water in excess of minimum irrigation applications could be applied. If one assumes that the Penman equation for estimating evapotranspiration at this site is accurate at approximately 42 inches, and the average annual precipitation ranges from 12-14 inches, then 28-30 inches of annual application could be justified quite easily. It is interesting to note that the waste water application permit currently held by El-Mar estimates allows for a maximum of 28 inches annual application on the Grassvalley silty clay loam. In later comparisons of nutrient loading and crop removal by various crops, I will use minimum annual irrigation application (inches) required by crops as well as a possible permit value of 28 inches.

The number of irrigation cycles required for the production of alfalfa, grass hay or spring grain will vary as a function of soil type and crop (Table 6). Soils with higher cumulative available water holding capacity (AWC) such as the De Smet loam and the Grassvalley silty clay loam require fewer irrigation cycles, which is usually an advantage for production. The number of irrigation cycles required is calculated assuming a management allowed deficit (MAD) for a given crop. Alfalfa, grass hay and spring grain all have MAD values which are equivalent to 50% of the cumulative AWC in a management depth of 5 feet. For example, the De Smet loam with an AWC of 8-10 inches (Table 6) requires irrigation when the AWC drops to 4-5 inches. At that point, the manager would irrigate with a net application of 4-5 inches. Maximum sprinkler irrigation rates (in/hr) are calculated based on a soils permeability as a function of the net application desired (Montana Irrigation Guide, USDA-SCS). For the De Smet loam, a maximum sprinkler irrigation rate of 1.2 in/hr is recommended for a 4.5 inch application. For the Grassvalley silty clay loam, a maximum sprinkler application rate of 0.26 in/hr is recommended for a 4.5 inch application.

able 6. Irrigation cycles required and maximum sprinkler irrigation rate
r a net application of 50% AWC on a major soil series in the study area.

oil	AWC inches	Irrigation Cycles Required at 50% AWC MAD* alfalfa	grass	sp.grain	Net Application Per Cycle	Maximum Irrigation Rate at 50% AWC
e Smet	8 - 10	3.8	3.3	2	4.5	1.2in/hr
rantsdale	5 - 7	5.7	5	3	3.0	1.4in/hr
rassvalley	8 - 10	3.8	3.3	2	4.5	0.26in/hr
loiese	3 - 4	9.7	8.6	5.1	1.75	1.9in/hr

Total irrigation requirement for alfalfa = 17 inches, grass hay = 15 inches, and spring grain = 9 ches. An irrigation cycle is necessary when the AWC drops by 50%. This is termed the management llowed deficit (MAD).

NUTRIENT LOADING AND ESTIMATED CROP REMOVAL

Measurements of total N, inorganic N (sum of NH3-N, NO2-N, and NO3-N), total P, and PO4-P from the October 1989 Missoula Wastewater Treatment Plant Discharge Monitoring Report (Table 7) were used to calculate nutrient loading rates at various annual irrigation applications (Table 8 and 9). Annual irrigation applications ranging from 9 inches for spring grain crops to 28 inches for a probable upper permit limit resulted in total P loadings ranging from 8.5-26.6 lbs P/acre, and total N loadings ranging from 69-216 lbs N/acre. Although not all of the total N and total P will be available for plant uptake in the first year, it is necessary to use total element values to calculate total nutrient loading rates. Inorganic P as orthophosphate species (PO4) and inorganic N (NH4+ and NO3-) represent the plant available forms of these nutrients. However, organic P and organic N compounds will be eventually converted through microbial decomposition (mineralization) to inorganic P and inorganic N.

Table 7. Water chemistry data of final effluent used for calculations of nutrient loading.*

Total P	PO4-P	Total N	NO3 + NO2-N	NH3-N
-----------------	---mg/L---	-----------------	-----------------	-----------------
4.2	3.1	34	8.7	8.5

* summarized from Missoula Wastewater Treatment Plant Discharge Monitoring Report for October, 1989.

Table 8. Amount of total P and PO4-P applied per acre per year at minimum crop irrigation requirements based on October, 1989, effluent data.

Crop	Minimum inches required annually	Total P	PO4-P
		-----------lbs P/acre	-------------
Alfalfa	17	16.1	11.9
Grass Hay	15	14.2	10.5
Spring Grain	9	8.5	6.3
Permit*	28	26.6	19.7

* Permit at El-Mar estates as a possible annual water application.

Table 9. Amount of total N and inorganic N applied per acre per year at minimum crop irrigation requirements based on October, 1989 effluent data.

Crop	Minimum inches required annually	Total N	Inorganic N**
		------------------lbs N/acre	--------------
Alfalfa	17	131	66
Grass Hay	15	116	59
Spring Grain	9	69	35
Permit*	28	216	109

* Permit at El-Mar estates as a possible annual water application.
**Inorganic N assumed to equal N in either NH3, NO3- or NO2 forms.

Average values for N and P concentration in plant tissue can be used to estimate crop removal of nutrients. General guidelines for crop removal suggest that alfalfa will remove 60 lbs N and 6 lbs of P per ton dry matter (Table 10). For grass hay, approximately 25 lbs N and 5 lbs P are removed per ton of dry matter. Under irrigated conditions, a conservative estimate of dry matter production on these soils would be 4-6 tons per acre per year for alfalfa and grass hay. Consequently, alfalfa would be removing 240-360 lbs of N and 24-36 lbs of P per acre per year. Grass hay would remove 100-150 lbs N and 20-30 lbs P per acre per year. These calculations show that even at the high water application rate of 28 inches, either grass hay or alfalfa would require nearly 100% of the total P applied in the wastewater (e.g. see Table 8). Since not all of the applied P in the wastewater will be available to the crop, additional P may be required for optimum sustained yields.

If the amount of wastewater effluent to be applied was based solely on a P balance, justification could be made for applying as high as 50 to 60 inches annually. This would result in annual P loadings of 48-57 lbs P per acre and would ensure an adequate supply of P for a 4-6 ton per acre alfalfa or grass hay harvest. Phosphorus is relatively immobile in soils and is converted to insoluble solid phases within a short time after application. However, application of 50 to 60 inches of water annually would be difficult to justify and could result in transport of nitrogen below the root zone into shallow groundwater aquifers.

Alfalfa would remove only a fraction of the total N applied in the wastewater because a significant fraction of N removed by alfalfa would come from biological N2 (g) fixation. Addition of N in excess of 100-200 lbs/acre can be detrimental to alfalfa causing reduced yields and decreased inoculation efficiency. At an annual irrigation application of 28 inches, I would not expect the N additions to be problematic for alfalfa or water quality. Grass hay would remove approximately 100-150 lbs N per acre per year at a yield rate of 4-6 tons per acre. Consequently, it would not be difficult to justify an annual application of 109 lbs inorganic N per acre (216 lbs total N per acre) for grass hay.

Of the spring grain crops, wheat removes more N and P per bushel than barley or oats (Table 10). Assuming an average yield of 40 bushels per acre, wheat would remove approximately 70 lbs N/acre and 13 lbs P/acre.

Table 10. Estimates of the amounts of N and P removed per ton of dry matter for alfalfa and grass hay and per 40 bushels for wheat, barley and oats.

Crop	N	P
	------------lbs	--------------
Alfalfa	60	6
Grass Hay	25	5
Wheat	70	13
Barley	49	8
Oats	34	6

FINAL RECOMMENDATIONS

1. *Soils*

Prime farmland in the study area is represented by the De Smet and Grantsdale loams, approximately 30 percent of the study area. I would recommend as a first choice the De Smet series since it has a higher water holding capacity and adequate permeability. There are approximately 1283 acres in the study area mapped as De Smet loams, existing primarily as large blocks in sections 12, 13, and 14 (13N, 20W).

The Grassvalley silty clay loam would also be an acceptable soil for wastewater application. I would avoid slopes in excess of 8 % which excludes mapping units 47 and 48. These slopes are highly sensitive to erosion and it would be wise in a wastewater application site to avoid significant amounts of runoff. Selected portions of mapping unit 46 which are the Grassvalley soils with 4-8% slopes would be acceptable but I would caution that the risk of erodibility is still high. Grassvalley soils on 0-4% slopes (mapping unit 45) would be good choices for waste water application. These soils have excellent waterholding capacity and would require fewer irrigation cycles than Grantsdale loam. The only disadvantage of the Grassvalley silty clay loam is the lower permeability which requires slower irrigation rates during each application.

One of the potential irrigation sites which was originally marked on the study area was located in section 4 (13N, 20W). Most of the soils just west of the Grassvalley Ditch in section 4 are mapped as Aquic Haploxerolls, Aquolls or Aquepts, which is to say they have extremely high seasonal water tables ranging from near the surface to 30 inches. I would avoid these soils as possible application sites because there is too much risk of water quality problems associated with shallow groundwater aquifers.

If one were to limit the choice of soils to the De Smet loam, the Grassvalley silty clay loam (0-4% slopes) and the Grantsdale loam there is still approximately 3114 acres available for consideration within the study area; and much of this acreage is in the east half of the study area in close proximity to the treatment plant.

2. *Water Application*

Estimates of consumptive use by the primary crop alternatives in the study area and estimates of evapotranspiration suggest that 24 to 27 inches of water will be utilized annually. However, effective precipitation during the growing season and stored soil moisture from non-growing season precipitation must be considered in the water budget. When these considerations are made a minimum irrigation application required for optimum yields of alfalfa or grass hay would be closer to 15 inches annually. One estimate of evapotranspiration (Penman equation) at this site was as high as 42 inches. Subtracting 12 to 14 inches of annual precipitation suggests that application rates could be as high as 28-30 inches annually. I would recommend 28-30 inches as an upper limit for annual waste water application on the De Smet and Grassvalley soils. Water applied in excess of consumptive use demand or evapotranspiration becomes available for movement and this may create a water quality problem with nitrate or phosphorus transport into shallow groundwater aquifers.

Interestingly, El-Mar Estates currently holds a permit for wastewater disposal of a maximum of 28 inches per year on the Grassvalley silty clay loam (4-8% slope). This site is located in mapping unit 46 in section 16, 13N, 20W (personal communication, Chip Johnson, and Mike Snavely, Missoula, MT). If one assumes an annual application of 28-30 inches, then 1360-1460 acres would be required to dispose of the equivalent of 9 million gallons per day for four months (May 15-Sept. 15). It seems reasonable to assume that these acres could be located on optimum soils in close proximity to the treatment plant.

3. *Crop Alternatives*

I would recommend either alfalfa, grass hay or alfalfa-grass hay mixtures. One must realize that final choices on crop management will probably be negotiated with the land owners. However, both alfalfa and grass hay have high consumptive use demand compared to spring grains, and both have fairly high removal rates of N and P. At an annual application of 28-30 inches of wastewater, these crops should be capable of removing the majority of N and P applied.

Spring planted grains have lower consumptive use demand and remove lower levels of nutrients, so I would not recommend wheat, barley or oats as continuous crops on wastewater application sites. Remember that during most alfalfa or grass hay rotations, grain may be planted once every 5 to 7 years depending on climatic conditions. However, for maximum water and nutrient use I would intensively manage a straight legume or grass crop or a mixed legume-grass crop. Assuming annual dry matter production of 4-6 tons, N and P removal should be similar to N and P applied in the wastewater effluent.

4. *Chemistry of Final Effluent*

After examining the Missoula Wastewater Treatment Plant Discharge Monitoring Report and the Monthly Laboratory Data Report for the month of October, 1989. I see no reason why the final effluent should not bee suitable for irrigation on crop land. The pH of the final effluent ranges form 6.9-7.2 which is excellent. The phosphorus and nitrogen levels are well documented and this data will be necessary for further refinements of nutrient loading rates during Phase II of the study.

In addition, I took one sample of the final effluent during my visit to Missoula with Mike Fraser and submitted this sample to the MSU Soil Analytical Laboratory for analysis of electrical conductivity (EC), sodium adsorption ratio (SAR)* and the soluble cations Ca, Mg, and Na. It appears from this single observation that the EC and SAR are well below the levels considered problematic for irrigation waters. If EC values exceed 2-4 mmhos/cm, then salinity problems can develop after continuous irrigation-evaporation cycles. The EC of the final effluent was 0.7 mmhos/cm which should not present any salinity hazard. The SAR, (calculated from soluble Na, Mg and Ca) of the final effluent was 2.2. Irrigation waters with SAR values greater that 15 are considered unsuitable for irrigation because of the soil physical dispersion problem encountered with high exchangeable Na.

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* SAR = [Na+]/([Ca2+] + [Mg2+])1/2 where concentrations are in mmol/L

Prior to submitting a permit application we will have to conduct a more detailed analysis of the wastewater effluent composition. The data for nitrogen and phosphorus averages will already be available; however, further work will be necessary on the levels of trace elements in the effluent.

APPENDIX

Soil Survey Map of Study Area

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MISSOULA LAND APPLICATION STUDY
PHASE I TASK C
RAPID INFILTRATION ALTERNATIVE

Prepared For:
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January 24, 1990

INTRODUCTION

Spratt & Associates (SA) was retained by Thomas, Dean and Hoskins, Inc. to evaluate the hydrologic implications of various land treatment alternatives potentially feasible for the treatment and disposal of wastewater from the secondary waste water treatment plant for the City of Missoula, Montana. This report summarizes the findings of SA on the potential use of rapid infiltration basins, at least seasonally, to polish treated wastewater in the Missoula Valley within the area defined on Figure 1. The objectives of this report are:

- Evaluate the study area for potential Rapid Infiltration (RI) Basin sites based upon existing information.
- Assess existing State and Federal regulations relating to construction and operation of RI basins with respect to use of this treatment alternative in the study area.
- Screen potential sites and select the "best" location.
- On one selected site, conduct a site analysis including: potential groundwater mounding, potential treatment of injected effluent and degradation of the underlying aquifer.

LOCATION

The study area defined on Figure 1, is located approximately 1.25 miles west of Missoula, Montana, in Missoula County. The study area consists of approximately 12 mi.^{2} generally bordered on the south and west by the Clark Fork River, Reserve Street on the east and U.S. Highway 10 on the north. Specifically, the study area consists of sections 1,2,3,4,9,10.11,12, 13 and parts of sections 14,

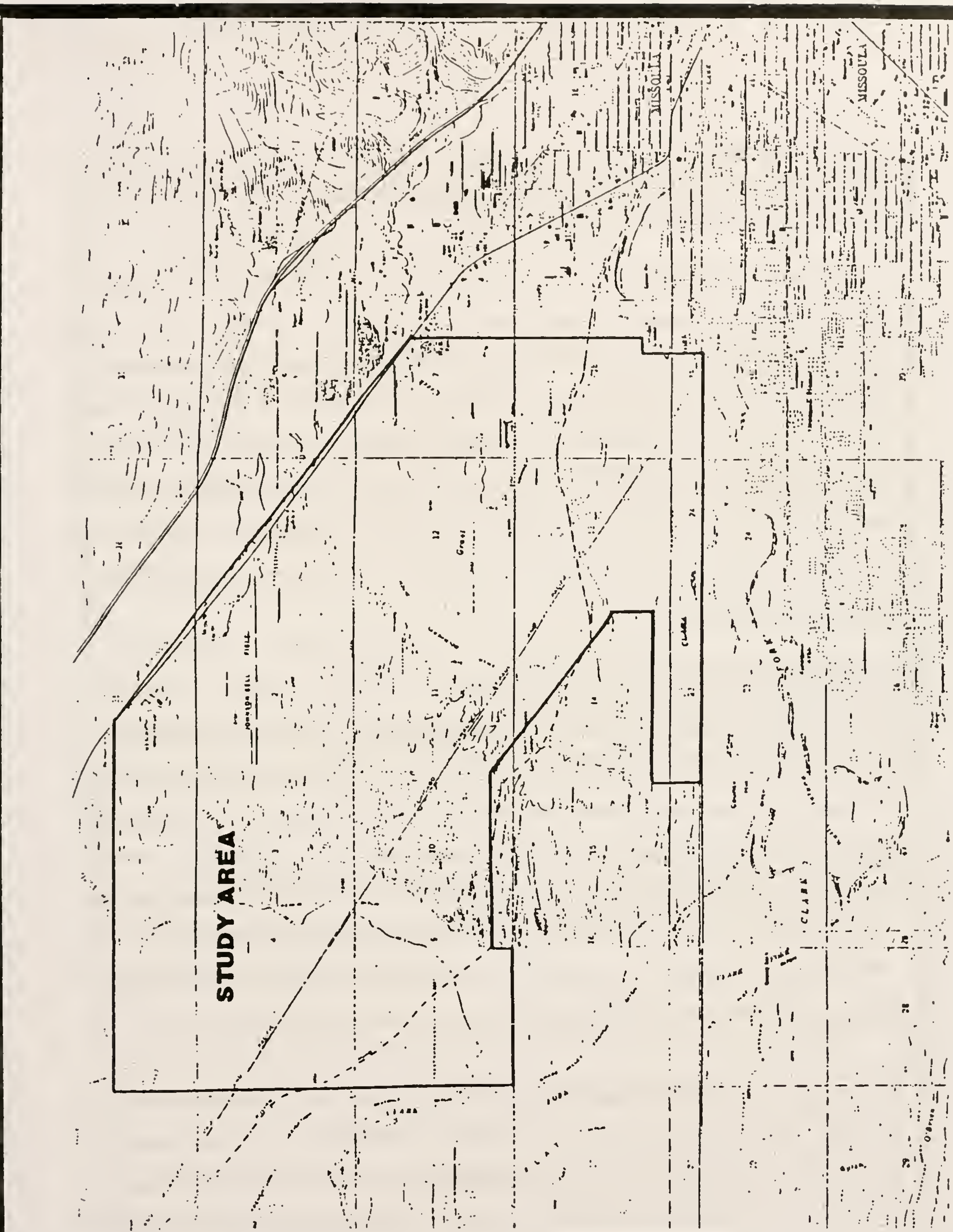

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FIGURE 1. Vicinity Map.

23, and 24 of T13N, R20W. Parts of sections 33, 34, and 35 of T14N, R20W and sections 7, 18, and 19 of T13N, R19W are also included.

HYDRAULIC CONDITIONS

The design flow volume is 9 million gallons per day (mgd). The principle purpose of utilizing a land treatment alternative for wastewater renovation by the City of Missoula is to control the amount of phosphorus reaching the Clark Fork River annually through the discharge of treated wastewater into the river. The treatment system may be operated for all or part of the year. Initial analysis assumes use of the RI basins year-round. Basin size does not change if the period of use is changed. Basin size can only be reduced by reducing the treated volume of effluent.

RAPID INFILTRATION BASIN FUNCTION

Municipal RI systems have been in successful operation in the United States for up to 100 years. Successful systems are located in East Glacier and Corvallis, Montana. The treatment concept depends on a relatively high rate of wastewater infiltration into the soil followed by rapid percolation, either vertically or laterally, away from the application point. The best soils are relatively coarse textured, with moderate to rapid permeabilities. In practice, wastewater application rates have ranges from about 50-400 ft/yr for successful RI systems. In contrast the typical loading on an agricultural system using wastewater might be 3-6 ft/yr.

RI systems are typically earthen basins designed for a repetitive cycle of flooding, infiltration/percolation, and drying. The duration of these cycles is a function of wastewater and soil characteristics, climatic conditions, and treatment goals. The percolate from cyclic RI systems is often suited for indirect re-use for many purposes. If this percolate emerges in an adjacent surface water, it should be of a high quality, equivalent to that obtained with complex and costly advanced waste treatment (AWT) systems.

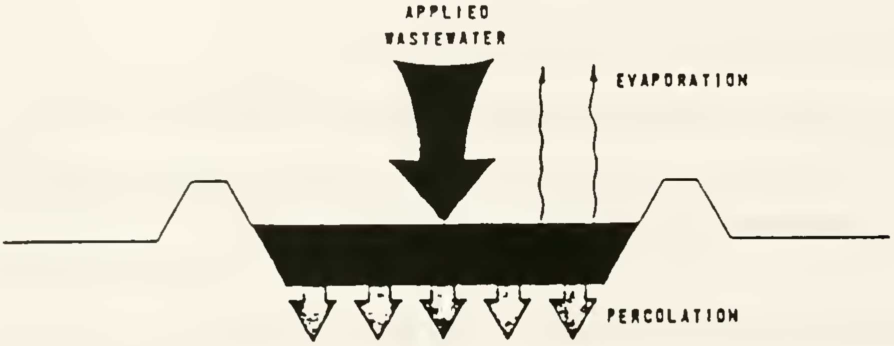
In RI land treatment, the wastewater is applied to rapidly permeable soils, such as sands and loamy sands, by spreading in basins or by sprinkling, and is naturally treated as it travels through the soil matrix. Most of the applied wastewater percolates through the soil eventually reaching the groundwater. Vegetation is not usually used to obtain additional treatment, but there are occasional exceptions.

The schematic view in Figure 2 shows the typical hydraulic pathway for rapid infiltration. A much greater portion of the applied wastewater percolates to the groundwater than with slow rate land treatment (irrigation). There is little or no consumptive use by plants and less evaporation by way of a reduced surface area.

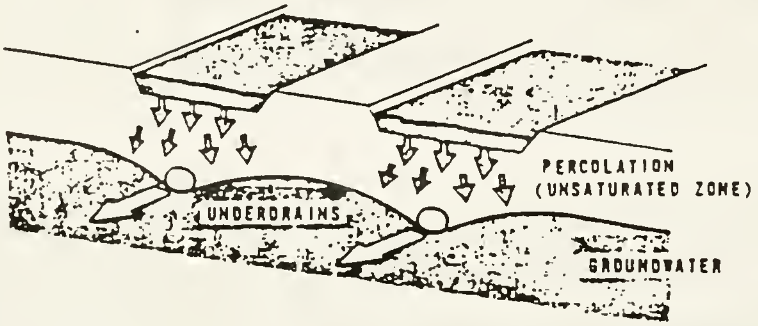
Removal of wastewater constituents by the filtering and straining action of the soil are excellent. Suspended solids, BOD, and fecal coliforms are almost completely removed in most cases.

Nitrogen removal is generally poor unless specific operating procedures are established to maximize denitrification. Field measurements of total nitrogen removal indicate a typical removal level of 30%. Increased removal rates can be achieved by: (1) adjusting application cycles, (2) supplying an additional carbon source, (3) using vegetated basins, (4) recycling the portions of the renovated water containing high nitrate concentrations, and (5) reducing application rates.

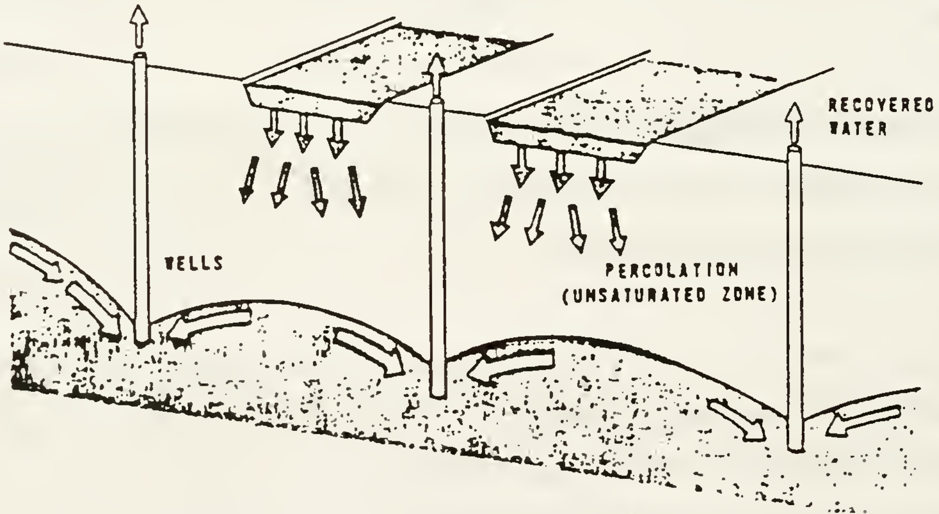
RAPID INFILTRATION



(a) HYDRAULIC PATHWAY



(b) RECOVERY OF RENOVATED WATER BY UNDERDRAINS



(c) RECOVERY OF RENOVATED WATER BY WELLS

After EPA, 1984

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FIGURE 2. Typical Hydraulic Pathway.

Combinations of these practices can increase nitrogen removal due to denitrification to a maximum of about 50%. Although total nitrogen removals may be poor, rapid infiltration is an excellent method for achieving a nitrified effluent.

Phosphorous removals can range from 70 - 90%, depending on the physical and chemical characteristics of the soil. The primary removal mechanism is adsorption with some chemical precipitation, so the long-term capacity is limited by the mass of soil in contact with the wastewater. Removals are also related to the residence time of the wastewater in the soil and the travel distance.

Infiltration of municipal waste water in rapid infiltration basins provides effective treatment of many types of water pollution. They can effectively remove or convert large quantities of pollutants including: organic matter, suspended solids, metals and excess nutrients. This reduction is accomplished by diverse treatment mechanisms: sedimentation, filtration, chemical precipitation and adsorption, microbial interactions, and uptake by vegetation.

Basic information on the performance of RI systems can be found in numerous published reports. The percolate, after a few meters of travel in the soil, is often sufficiently renovated to permit recovery and re-use for unrestricted agricultural irrigation is acceptable. RI systems can also be managed to satisfy nitrogen and other drinking water limitations in the the percolate, but direct on-site recovery and re-use as potable water without extensive further treatment is not recommended.

PLANNING AND SITE SELECTION

Preliminary site selection was based on the analysis of existing information including: soil and ground water conditions, grades, existing land use, and flood potential. During the engineering evaluation, economic considerations will be added.

LAND AREA REQUIREMENTS

Preliminary estimates of the required RI basin size were developed as follows. Assuming preapplication treatment of wastewater to be the equivalent of primary treatment plant quality:

$$A_{ri} = kQ_m$$

Where: A_{ri} = field area for treatment, acre

Q_m = design average monthly flow, gal/month

$k = 4.8E - 7$

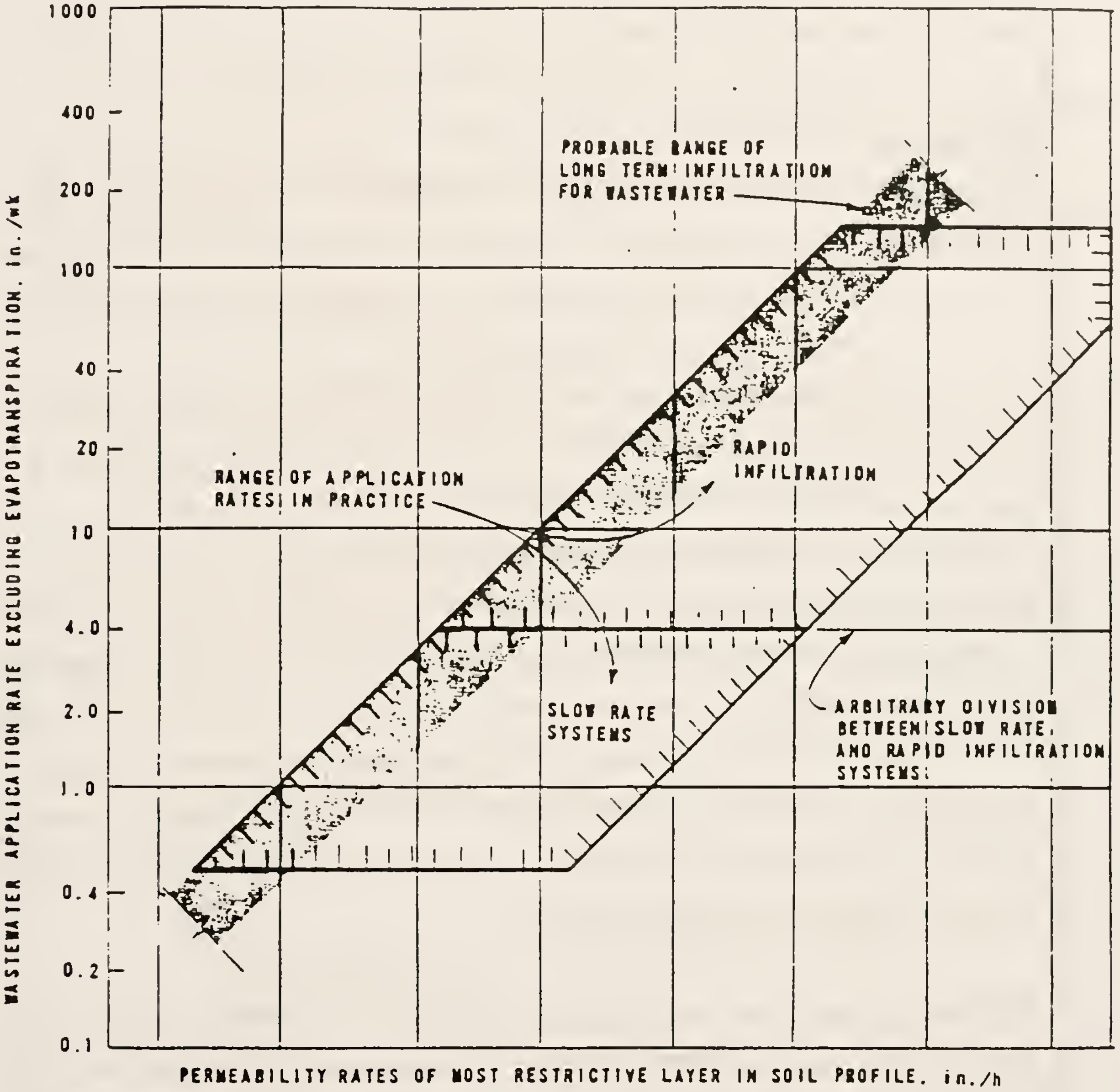
[Reed, Middlebrooks and Crites 1988]

$A_{ri} = 131.40$ acres

An alternative approach can be based on the minimum reported infiltration rate [SCS 1985], the annual wastewater effluent volume and a safety factor [U.S.EPA 1984]. This method yields an estimated required area of 230 ac.

Figure 3 relates the clean water permeability of the most restricting layer in the soil profile to the design wastewater percolation rate. The basin size resulting from the above alternative method results in a loading rate of 10.1 in/wk, which lies within the "probable range for long-term infiltration for wastewater" (Figure 3) as experienced by previous projects. Therefore, for preliminary analysis, a 230 ac. RI basin will be utilized. This estimate is intended for preliminary calculations

SOIL PERMEABILITY VERSUS RANGES OF APPLICATION RATES FOR SLOW RATE AND RAPID INFILTRATION TREATMENT



PERMEABILITY* SOIL CONSERVATION SERVICE DESCRIPTIVE TERMS						
VERY SLOW	SLOW	MODERATELY SLOW	MODERATE	MODERATELY RAPID	RAPID	VERY RAPID
< 0.06	0.06-0.20	0.20-0.60	0.60-2.0	2.0-6.0	6.0-20.0	> 20.0

* MEASURED WITH CLEAR WATER

1 in./wk = 2.54 cm/wk

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FIGURE 3. Permeability.

only, and is not valid for final design.

REGULATORY FACTORS

The percolate from RI systems may not in some cases satisfy all factors in state groundwater quality requirements. When such is the case, there are two options:

- Design for percolate recovery, via underdrains or wells, for subsequent re-use or surface discharge.
- Demonstrate via a hydrogeological survey and analysis that all of the percolate will emerge as base flow in an adjacent surface water or otherwise not adversely impact the in situ aquifer.

Two rules are of paramount importance when designing a RI system in the Missoula Valley. State of Montana groundwater quality regulations (ARM 16.20.1001 et seq.) include a non-degradation clause (ARM 16.20.1011) which, in essence, precludes the addition of any contaminant that has the affect of increasing the concentration of that contaminant in the receiving groundwater above the ambient level. Secondly, the project area is part of a designated sole source aquifer. If any federal funds are used to construct this project, the project plans must be reviewed and approved by EPA.

The Sole Source Aquifer program was established under Section 1424 (e) of the Safe Drinking Water Act (SDWA) of 1974. The program provides for EPA review of Federal financially-assisted projects planned for the area to determine their potential for contaminating the aquifer. Based on this review, no commitment of Federal financial assistance may be made for projects "which the Administrator determines may contaminate such aquifer," although Federal funds may be used to modify projects to ensure that they will not contaminate the aquifer [U.S. EPA 1987].

Review of Floodplain Management regulations adopted by the State of Montana (ARM 36.15.101 et seq.) prohibits the installation of sewage treatment facilities in the designated 100-yr floodplain and requires a permit for such systems installed in the flood fringe.

SITE CHARACTERISTICS

Sites with significant and numerous changes in relief over a small area are not the best choice for RI basins. A significant clay fraction (>10%) in the soil would generally exclude RI construction on fill using such materials [U.S.EPA 1984]. Extremely non-uniform soils over the site area do not absolutely preclude development for an RI system, but they significantly increase the cost and complexity of site investigation. Special site requirements for RI basin location are listed in the following table.

Table 1. Rapid Infiltration Basin Site Requirements

Parameter	Limit
Soils	sandy loams and sands
Permeability	>2 - 19.7 in/hr
Bedrock & Groundwater	>14.8 ft.
Slope	<10%
Location	near surface waters or over non-drinking water aquifers

[Reed, Middlebrooks and Crites 1988]

DESIGN CONSIDERATIONS

HYDRAULIC LOADING RATE AND BASIN AREA

The hydraulic loading rate is based directly upon the field and laboratory test results for infiltration, permeability, and hydraulic conductivity. For preliminary evaluation of the sites, published data will be used [TDH 1989].

If the site investigation reveals a specific layer of soil that will restrict flow, the design is based on the hydraulic conductivity of that layer regardless of its thickness. If there is not an obvious restricting layer, the "effective" hydraulic conductivity of the profile is the mean (arithmetic, harmonic, or geometric) of the values observed. A small percentage of this "effective" hydraulic conductivity is then taken as the design loading rate. The percentages used are based on historically successful RI performance and allow for wastewater characteristics, soil reactions, and the need for cyclic operation.

Table 2. Design Factors For Hydraulic Loading

Test Procedure	Adjustment Factor for Annual Loading Rate
Basin flooding test	10 -15% of "effective rate observed
Air entry permeameter and cylinder infiltrometers	2 - 4% of "effective" rate observed
Laboratory permeability measurements	4 - 10% of "effective" rate observed, or of restricting soil layer.

The hydraulic conductivity defines the amount of clean water that can move through a unit cross-section in the soil, at unit gradient and under saturated conditions. The clean water rate, L_{cw}

$$L_{cw} = \frac{(K_v)\,(24\ \text{h/d})\,(365\ \text{d/yr})\,(1\ \text{ft}^2)}{(12\ \text{in/ft})}$$

Where $K_v = 0.6$ in/hr, $L_{cw} = 438$ ft/yr
K_V = Vertical hydraulic conductivity

An annual basis is used for the loading rate determination, since it is assumed that wastewater will be applied on some sort of regular schedule throughout the year. To determine the design loading rate:

Annual Wastewater Loading, L_{ww}

$$L_{ww} = (SF)\ (L_{cw})$$

Where L_{cw} = 438 ft/yr,
SF = 0.10 (Selected from Table 2)
L_{ww} = 43.8 ft/yr (0.12 ft/day)

The safety factor is only used to determine the annual hydraulic loading. It is not appropriate to adjust either K_V or K_h (horizontal hydraulic conductivity) with these factors for shorter time periods. Such adjustments do not define the unit rates for infiltration or subsurface flow. These equations are inappropriate for specific loading cycle estimates.

Determination of the annual loading rate is, in effect, a definition of the capacity of the site to transmit wastewater if applied at some undefined, but regular schedule throughout the year. If some winter storage is required or there are seasonal constraints on operation, the annual loading is proportionally reduced to account for the non-operating period.

LAND AREA REQUIRED

The required application area for RI systems can be determined with previously stated equations. The area calculated with these equations is the surface area that is needed for infiltration in the final system. As described in a previous section, the preliminary estimate of land area required for proposed RI basins is 230 acres.

WET/DRY RATIO

A regular drying period is essential for the successful performance of RI systems. Where maximum hydraulic loading and/or nitrification are the objective, the ratio might be 0.2 or less. When nitrogen removal is necessary, the ratio ranges from 0.5 to 1.0. Typical cycle periods are shown in Figure 4. For this preliminary analysis, no cycle period was selected.

APPLICATION RATE

The selected wet/dry cycle is combined with the "annual" hydraulic loading to determine the unit application rate. Assuming the wastewater has similar characteristics all year, the amount applied per cycle is the same and summer/winter drying periods relied on for restoring the infiltration rate. As a general "rule-of thumb" the unit application rate is usually less than 50% of the K_v to allow for initial clogging by wastewater solids and organics, if optimization of hydraulic loading is the design goal. Even if the application rate (R) is higher, ponding will not typically commence until the later part of short flooding cycles. For this preliminary analysis, the lowest estimate of K_v was used for analysis purposes to provide conservative estimates. During design, the adjustment procedure above would be applied to site specific field derived data.

TYPICAL HYDRAULIC LOADING CYCLES [11]

Location	Loading objective	Application period	Resting period	Bed surface
Calumet, Michigan	Maximize infiltration rates	1-2 d	7-14 d	Sand (not cleaned)
Flushing Meadows, Arizona				
Maximum infiltration	Increase ammonium adsorption capacity	2 d	5 d	Sand (cleaned) and grass cover[a]
Summer	Maximize nitrogen removal	2 wk	10 d	Sand (cleaned) and grass cover[a]
Winter	Maximize nitrogen removal	2 wk	20 d	Sand (cleaned) and grass cover[a]
Fort Devens, Massachusetts	Maximize infiltration rates	2 d	14 d	Grass (not cleaned)
Fort Devens, Massachusetts	Maximize nitrogen removal	7 d	14 d	Grass (not cleaned)
Lake George, New York				
Summer	Maximize infiltration rates	9 h	4-5 d	Sand (cleaned)[a]
Winter	Maximize infiltration rates	9 h	5-10 d	Sand (cleaned)[a]
Tel Aviv, Israel	Maximize renovation	5-6 d	10-12 d	Sand[b]
Vineland, New Jersey	Maximize infiltration rates	1-2 d	7-10 d	Sand (disked), solids turned into soil[c]
Westby, Wisconsin	Maximize infiltration rates	2 wk	2 wk	Grassed
Whittier Narrows, California	Maximize infiltration rates	9 h	15 h	Pea gravel

a. Cleaning usually involved physical removal of surface solids.

b. Maintenance of sand cover is unknown.

c. Solids are incorporated into surface sand.

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FIGURE 4. Typical Loading / Drying Periods.

SUBSURFACE FLOW AND GROUNDWATER MOUNDING

Groundwater mounding beneath the basin occurs until sufficient hydraulic gradient has been developed to move water away from beneath the basin in a lateral direction. Transient mounding is inevitable and acceptable so long as it does not interfere with infiltration at the basin surface and dissipates quickly enough to allow for aerobic restoration of the near surface profile.

SUBSURFACE FLOW. Percolate flow in the unsaturated zone beneath an RI basin is essentially vertical and K_v controls flow. If a groundwater table, impeding layer, or barrier exists at depth, a horizontal component is introduced and flow is then controlled by some combination of K_h and K_v within the groundwater mound or perched mound. At the margins of the groundwater mound, and beyond, the flow is typically lateral and K_h controls.

The capability for lateral flow away from the application site controls the extent of mounding that will occur beneath the basins. The "space" available for lateral flow is the underlying aquifer and the zone between the existing groundwater table, or other barrier, and whatever point is selected as an acceptable depth beneath the ground surface. The proposed basin location is plotted on Figure 5. An analysis, based on that location and information described in this report, was conducted to insure that the adjacent profile has the capacity for lateral transmissions of the applied wastewater. Results of the analysis are described later in this report. The first zone of concern is the perimeter around the general basin area, since this may directly influence mounding. The analysis considers the gradients and potential for flow in various directions away from the site, in addition to the loading schedules for various basins to estimate what proportion of the

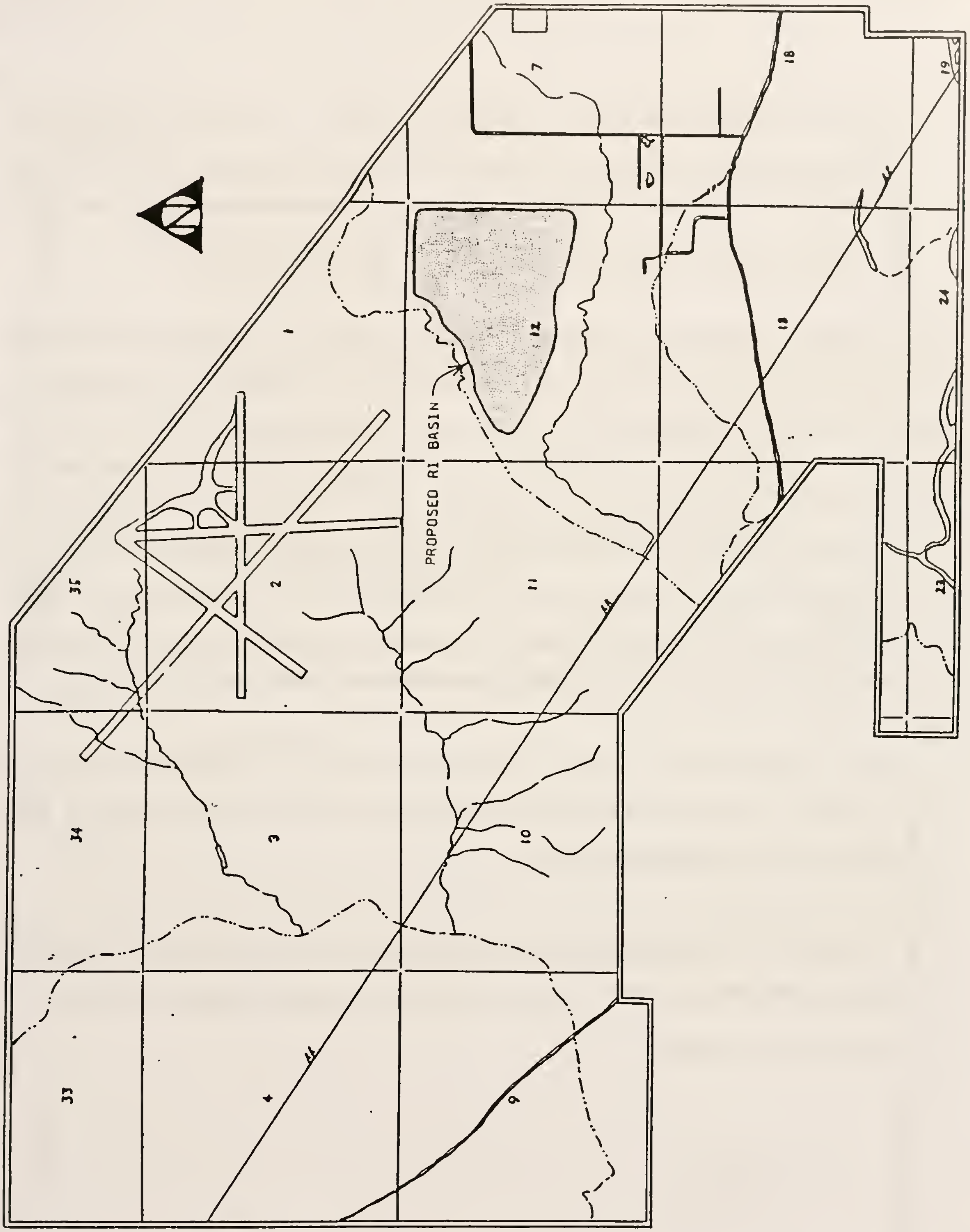

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FIGURE 5. Proposed RI Basin Location.

applied wastewater will flow in a particular direction. The general analysis employs potential flow theory. The use of this theory to construct flow lines in the presence of a uniform flow field of constant thickness represents a reasonable first approximation of what takes place down-gradient of the mound.

In many cases the RI percolate emerges as base flow in adjacent surface water and it is necessary to predict the position of the groundwater table between the RI basins and that point of emergence. This will reveal if seeps or springs are likely to develop in the intervening terrain. Various models can be used to estimate the saturated thickness of the water table at any point down-gradient of the basin area. Due to its flexibility, MODFLOW was used to estimate water table elevations and thus predict potential interception of the ground surface by the RI percolate. This same information was also incorporated into a contaminant transport model to estimate down-gradient impacts due to RI basin percolate.

The answers from all of these models are meaningless unless the soil and hydraulic parameters and boundary conditions of the site match reasonably well with those of the model selected.

The travel time for lateral flow is a function of the hydraulic gradient, the distance, the K_h, and the porosity of the soil. The following equation [U.S.EPA 1984] can be used for this purpose.

$$t_D = \frac{(n)\,(D)^2}{K_h\,(h_o - h_i)}$$

where:

t_D = travel time for lateral flow from basin area to emergence in surface waters, d

n = porosity of soils, % (as decimal; calculated from field data) (n = 0.20 [Woessner 1988])

D = travel distance, ft (D = 1,400 ft, based on flow line projected on water table map Figure 9)

h_o = saturated thickness of aquifer at RI basin area, ft (h_o = 120 ft [Woessner 1988])

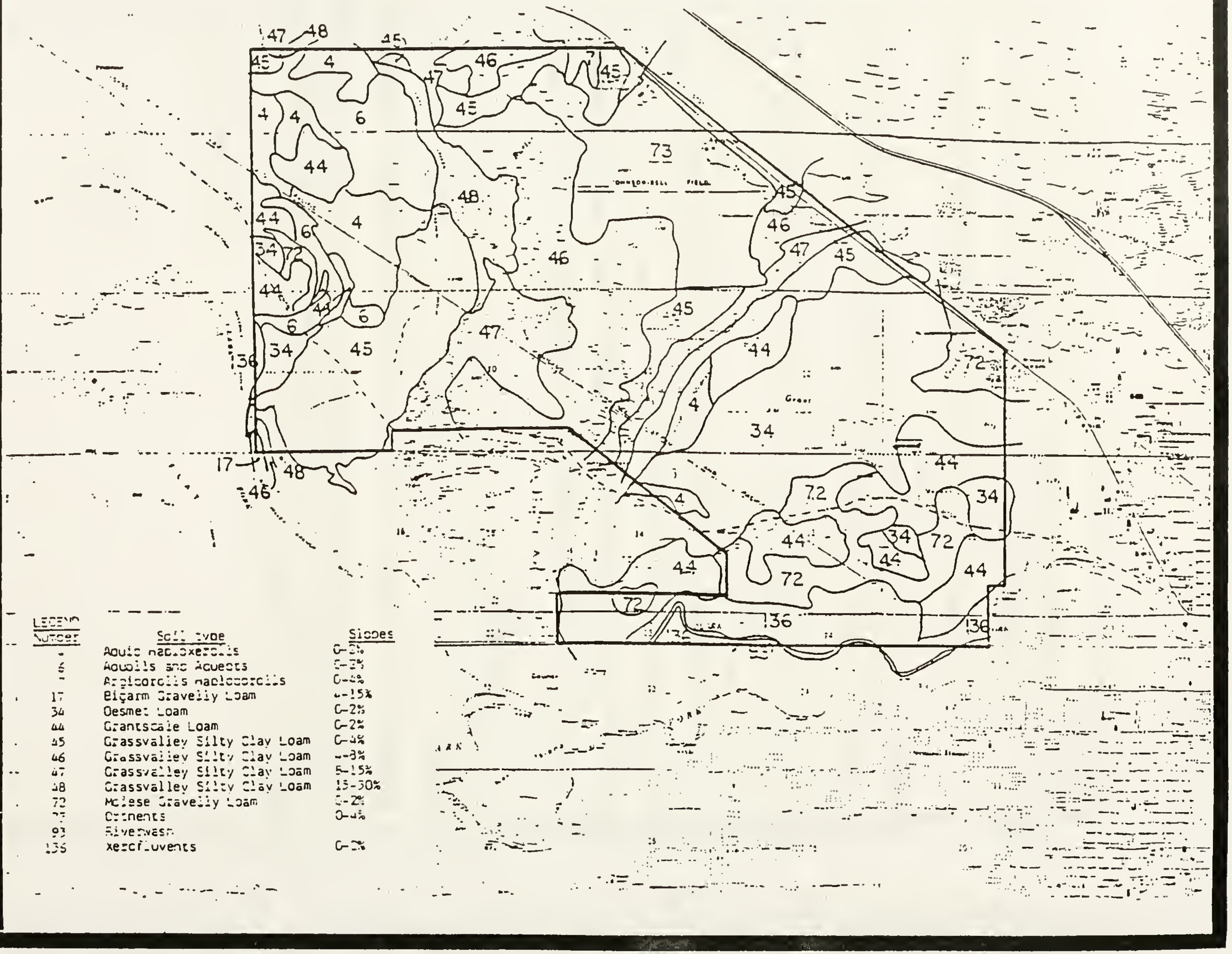
h_i = saturated thickness of aquifer at point of emergence (h_i = 119 ft [Woessner 1988])

K_h = effective horizontal conductivity of the soil system, ft/d (units must be consistent) K_h = 1,283 ft/day

t_D = 305.5 days

SOILS

Detailed soil investigations have been completed for soils within the study area. For basin design purposes, fundamental soil characteristics are critical. Soils mapping completed by the Soil Conservation Service [SCS 1985] indicate soils in the study area are quite varied (Figure 6).



LEGEND Number	Soil Type	Slopes
4	Aquic Haploxerolls	0-2%
6	Aquolls and Aquepts	0-2%
7	Argiborolls Haploborolls	0-4%
17	Bigarm Gravelly Loam	4-15%
34	Desmet Loam	0-2%
44	Grantsdale Loam	0-2%
45	Grassvalley Silty Clay Loam	0-4%
46	Grassvalley Silty Clay Loam	4-8%
47	Grassvalley Silty Clay Loam	5-15%
48	Grassvalley Silty Clay Loam	15-30%
72	Moiese Gravelly Loam	0-2%
73	Orthents	0-4%
93	Riverwash	
136	Xerofluvents	0-2%

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FIGURE 6. Soils Map.

Table 3. Soil Types and Characteristics, Missoula Land Application Study Area.

Legend No.	Soil Type	Slope (%)	Clay (%)	Permeability (in/hr)	Depth to Seasonal Water Table (ft)
4	Aquic Haploxerolls	0 -2			1.6-3.3
6	Aquolls and Aquepts	0 -2			0-3
7	Argiborolls Haploborolls	0 -4	5 - 10	6 - 20	>6
17	Bigarm Gravelly Loam	4 - 15	5 - 18	2.0 - 6.0	>6
34	Desmet Loam	0 -2	10 - 18	0.6 - 2.0	>6
44	Grantsdale Loam	0 - 2	10 - 18	0.6 - 2.0	>6
45	Grassvalley Silty Clay Loam	0 - 4	40 - 60	<0.06	>6
46	Grassvalley Silty Clay Loam	4 - 8	40 - 60	<0.06	>6
47	Grassvalley Silty Clay Loam	8 - 15	40 - 60	<0.06	>6
48	Grassvalley Silty Clay Loam	15 - 30	40 - 60	<0.06	>6
72	Moiese Gravelly Loam	0 - 2	5 - 22	.6 - 2.0	>6
73	Orthents	0 - 4			
93	Riverwash	-			
136	Xerofluvents	0 - 2			

Clay percentage and permeability in the above table are based on reported values for the 12-18 inch zone for each soil type. If data is unreported, it was unavailable to the investigators. The first three soil types (Aquic Haploxerolls, Aquolls, and Aquepts) are not reviewed further due to high groundwater. The water table in these soils is too close to the soil surface for successful operation of RI basins.

The Argiborolls and Haploborolls consist of deep, well drained to excessively drained soils that formed in Tertiary sediment. These soils occur on terraces and foothills with slopes of 0 - 60% between 3,300 and 4,500 ft. MSL. The average annual precipitation is 13 - 16 in., average annual temperature 42 - 44 degrees F, and the frost-free season is 90 - 110 days. In general, these soils have a surface layer that is loam underlain by gravelly loam, very gravelly loam, gravelly silt loam or very gravelly silt loam. Below the surface layer, to a depth of 60 inches or more, textures range from extremely gravelly clay loam to clay.

The Bigarm series consists of deep, somewhat excessively drained soils that formed in alluvium and colluvium. These soils are on terraces, foothills, and mountain slopes. The slopes range from 0 - 60 %, elevation from 3,000 - 5,200 ft. MSL, average annual precipitation from 14 - 17 in., average annual air temperature from 42 - 45 degrees F, and the frost free season is 90 - 110 days. The A11 horizon is loam and contains 15 - 30 percent pebbles and 0 to 5 percent cobbles. The A12 horizon is loam and contains 35 to 45 percent pebbles and 0 - 15 percent cobbles. The A11 and A12 horizons are neutral. The B2 horizons are loam or sandy loam and contain 35 to 45 percent pebbles and 0 - 15 percent cobbles; they are slightly acid to mildly alkaline. The C horizon is loamy sand or sandy loam and contains 50 - 55 percent pebbles and 10 to 30 percent cobbles; it is neutral or mildly alkaline.

The DeSmet series consists of deep, well drained soils that formed in alluvium. These soils are on terraces in intermountain valleys. slope is 0 to 2 percent, elevation lies between 2,800 and 3,500 ft. MSL, with an average annual precipitation of 11 to 14 inches, and air temperature of 43 to 45 degrees F, with a frost free season of 105 to 120 days. The A1 or A_p horizon is loam and is neutral or mildly alkaline. The B2 horizon is loam or very fine sandy loam. The B3ca horizon is loam, silt loam, or very fine sandy loam. The C horizon is fine sandy loam or very fine sandy loam. The B2, B3ca, and C horizons are mildly alkaline or moderately alkaline.

The Grantsdale series consists of deep, well drained soils that formed in alluvium. These soils are on terraces in intermountain valleys. Slope is 0 to 2 percent. Elevation is 2,800 to 3,500 feet. The average annual precipitation is 11 to 14 inches, the average annual air temperature is 43 to 45 degrees F, and the frost free season is 105 to 120 days. The A_p horizon is loam. The B2 horizon is loam or silt loam. The A_p and B2 horizons are slightly acid or neutral. The B3ca horizon is loam or very fine sandy loam and is mildly alkaline or moderately alkaline. The IIC1ca and IIC2 horizons are loamy sand or sand and are 30 to 40 percent pebbles and 5 to 20 percent cobbles; they are mildly alkaline to strongly alkaline.

The Grassvalley series consists of deep, well drained soils that formed in glaciolacustrine deposits. These soils are on lake terraces. Slope is 0 to 30 percent. Elevation is 3,200 to 3,800 feet. The average annual precipitation is 11 to 14 inches, the average annual air temperature is 43 to 45 degrees F, and the frost-free season is 105 to 120 days. The A_p horizon is silty clay loam and averages 30 to 40 percent clay. It is neutral or mildly alkaline. The B2t horizon is clay or silty clay and averages 40 to 60 percent clay. It is neutral to moderately alkaline. The B3ca horizon is clay or silty clay and averages 40 to 60 percent clay. The C horizons are clay, silty clay, or silty clay loam and average 35 to 60 percent clay. The B3ca and C horizons are mildly alkaline or moderately alkaline.

The Moiese series consists of deep, excessively drained soils that formed in sandy and gravelly alluvium. These soils are on terraces and fans. Slope is 0 to 2 percent. Elevation is 2,800 to 3,500 feet. The average annual precipitation is 12 to 14 inches, the average annual air temperature is 43 to 45 degrees F, and the frost-free season is 105 to 120 days. The A_p horizon is loam and contains 15 to 35 percent pebbles; it is slightly acid or neutral. The B2 horizon is sandy loam and contains 35 to 45 percent pebbles and 0 to 15 percent cobbles; it is neutral. The C horizons are loamy sand, fine sand, or sand and contain 45 to 55 percent pebbles and 15 to 30 percent cobbles; they are neutral to moderately alkaline.

The Xerofluvents consist of deep, somewhat poorly drained to well drained soils that formed in alluvium. These soils are on flood plains. Slope is 0 to 2 percent. Elevation is 2,900 to 3,200 feet. The average annual precipitation is 11 to 14 inches, the average annual air temperature is 44 to 46 degrees F, and the frost-free season is 90 to 110 days. The surface layer to a depth of 13 inches ranges from loamy very fine sand to loam. Below a depth of 13 inches, the profile ranges from loam to extremely gravelly sand.

Based on Figure 6, the following soils have sufficient permeability to be potentially feasible for RI basin sites.

Argiborolls & Haploborolls
Bigarm Gravelly Loam
DeSmet Loam
Grantsdale Loam
Moiese Gravelly Loam

Slopes on the Bigarm gravelly loam may preclude its use for RI due to excessive construction costs. The clay percentage in all of these soils generally precludes the construction of RI basins on fill composed of these soils. Soils that meet the minimum requirements for Ri basins are unshaded on Figure 7.

SITE SELECTION

Several published reports proposed a numerical rating system to coordinate site selection [U.S. EPA 1981; U.S.EPA 1984; Reed, Middlebrooks and Crites 1988]. As part of

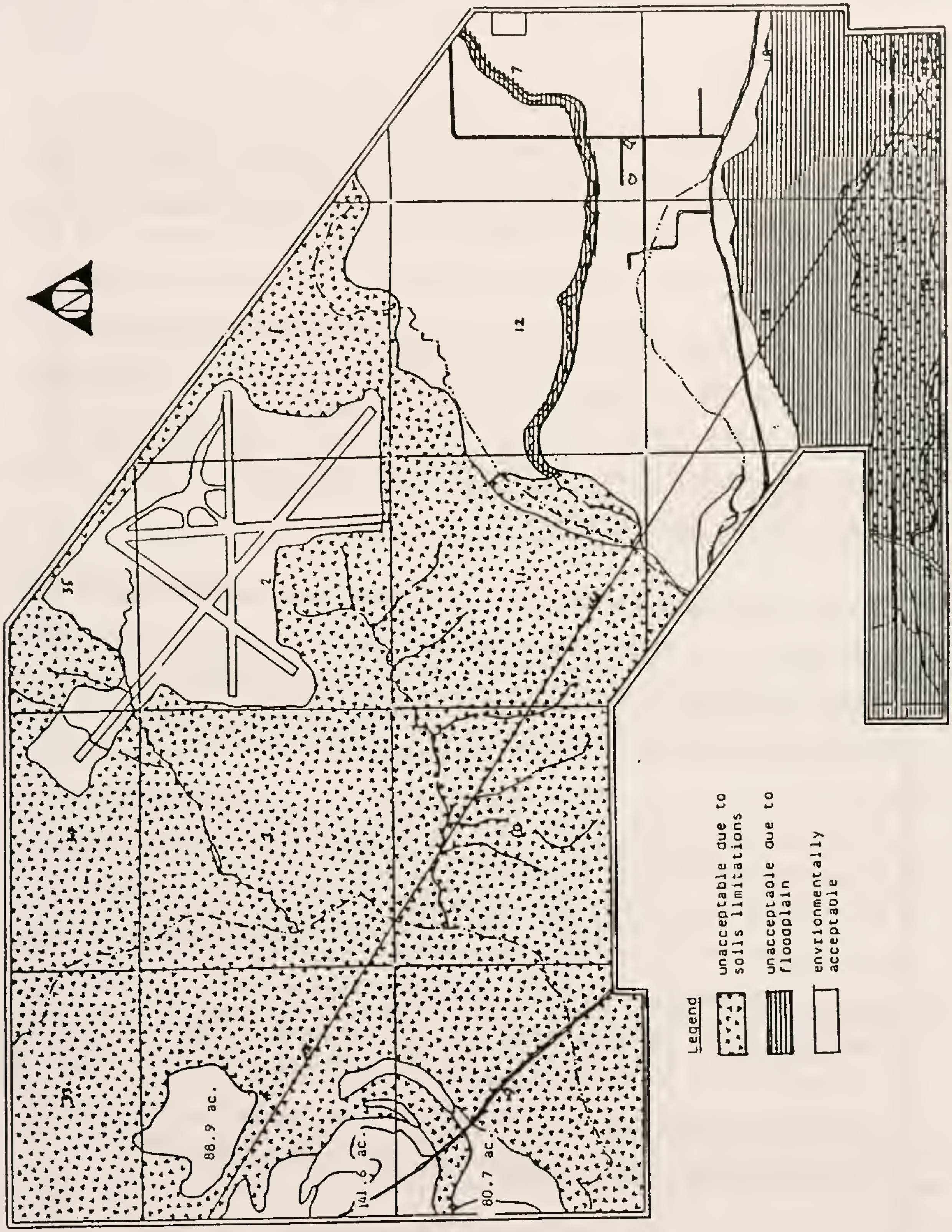
N
35
2
11
12
1
34
3
10
33
88.9 ac.
141.6 ac.
80.7 ac.
Legend
unacceptable due to soils limitations
unacceptable due to floodplain
environmentally acceptable

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FIGURE 7. Suitable Soils for RI Basins.

the numerical process, a number of map overlays are prepared along with preliminary estimate of required land area. Figure 7 illustrates the overlay process and shows the areas within the study area that are potentially feasible RI basin sites.

The first areas excluded were those with specific soils limitations of permeabilities <0.6 in/hr, seasonal water table elevations less than 10 ft below the soil surface and slopes greater than 4%. Next, the 100-yr floodplain boundary [FEMA 1988] was delineated with all lands within the boundary excluded. Three areas (shown on Figure 7) remained.

The area encompassed by the Johnson Bell Field (Airport) was excluded for this analysis due to construction limitations and distance from the STP. Such limitations do not preclude the use of the airport property for RI basins, detailed soils studies would be required to more accurately evaluate the site potential.

Soils in the cluster of parcels on the west and the large area on the east of the study area are the same. Therefore, due to proximity to the STP and potential availability of a single large tract on the eastern end of the study area, the area within Section 12, T13N, R20W was selected for preliminary evaluation. Soils within the proposed basin area are dominantly DeSmet Loam with some Grantsdale Loam on the northwest corner of the basin area, site slopes of 0 - 2%, permeabilities of 0.6 - 2.0 in/hr and depths to the water table >6 ft. Due to potential clay fractions greater than 10% this area will require detailed site evaluation prior to or during design to evaluate long-term operating characteristics.

GROUNDWATER MOUNDING

Infiltration of nine million gallons per day of treated waste water must cause mounding of the water table under the basin. When water percolates beneath a spreading basin, a mound in the water table is formed, as shown in Figure 8. The dimensions of this mound are governed by the basin size and shape, recharge rate and duration, and aquifer characteristics [Todd 1980]. To evaluate the mounding potential of the design loading rate of 9 mgd, a hypothetical basin was modeled with the USGS Modular Flow Model (MODFLOW) [McDonald and Harbaugh 1984]. For these simulations, version 3.2 issued October, 1989, was used. The model can simulate groundwater flow in three directions and can be configured to accommodate most hydrologically significant features of the study area. For this analysis, the model was configured to describe two dimensional flow.

For preliminary analysis, a single loading condition was simulated. It was a steady-state condition that assumed continuous loading of a 230 acre basin for infinite time. This model utilizes a simplified basin/aquifer relationship. A single layer model on a sloping surface was utilized. The steady state model assumes all boundaries are head dependent with constant heads on the north and south boundaries and flux boundaries on the east and west. In this steady state model, the loading period was assumed to be 365 days/year.

This model assumes the infiltration rate is exactly correct and utilizes the minimum basin area required to dispose of 9 mgd including a safety factor.

Transient state models can be developed that incorporate varying dose rates, for instance if the basin is only used 8 months of the year, then the mound will decay for those 4 months of non-use. A fluctuating background water table elevation can also be imposed on the model. Other conditions which can be incorporated

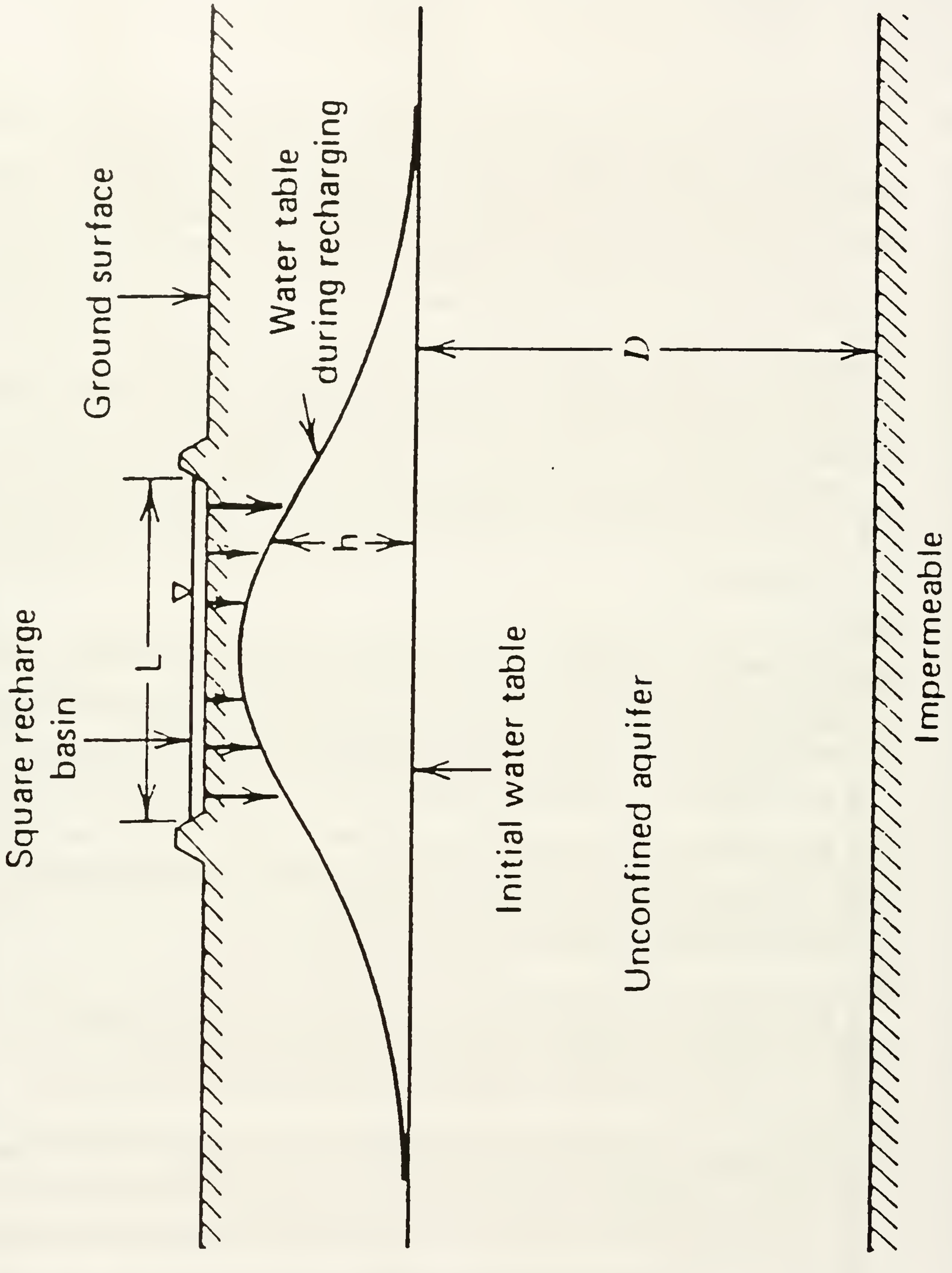

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FIGURE 8. Mounding Effect.

into the model are: sloping water tables, subsurface layers of reduced conductivity which give rise to perched mounds, and the presence of points of withdrawal (e.g. stream). While manual solutions can be obtained considering these various conditions, computer models are much preferred due to their greater accuracy and speed.

Well logs for wells located within the study area were obtained from DNRC Water Rights Bureau files. These 59 well logs are summarized in the Appendix. Figure 9 illustrates the estimated location of these wells. Contours reflect the estimated water table surface elevation based on static water levels reported in the well logs and ground elevations estimated from USGS topographic maps.

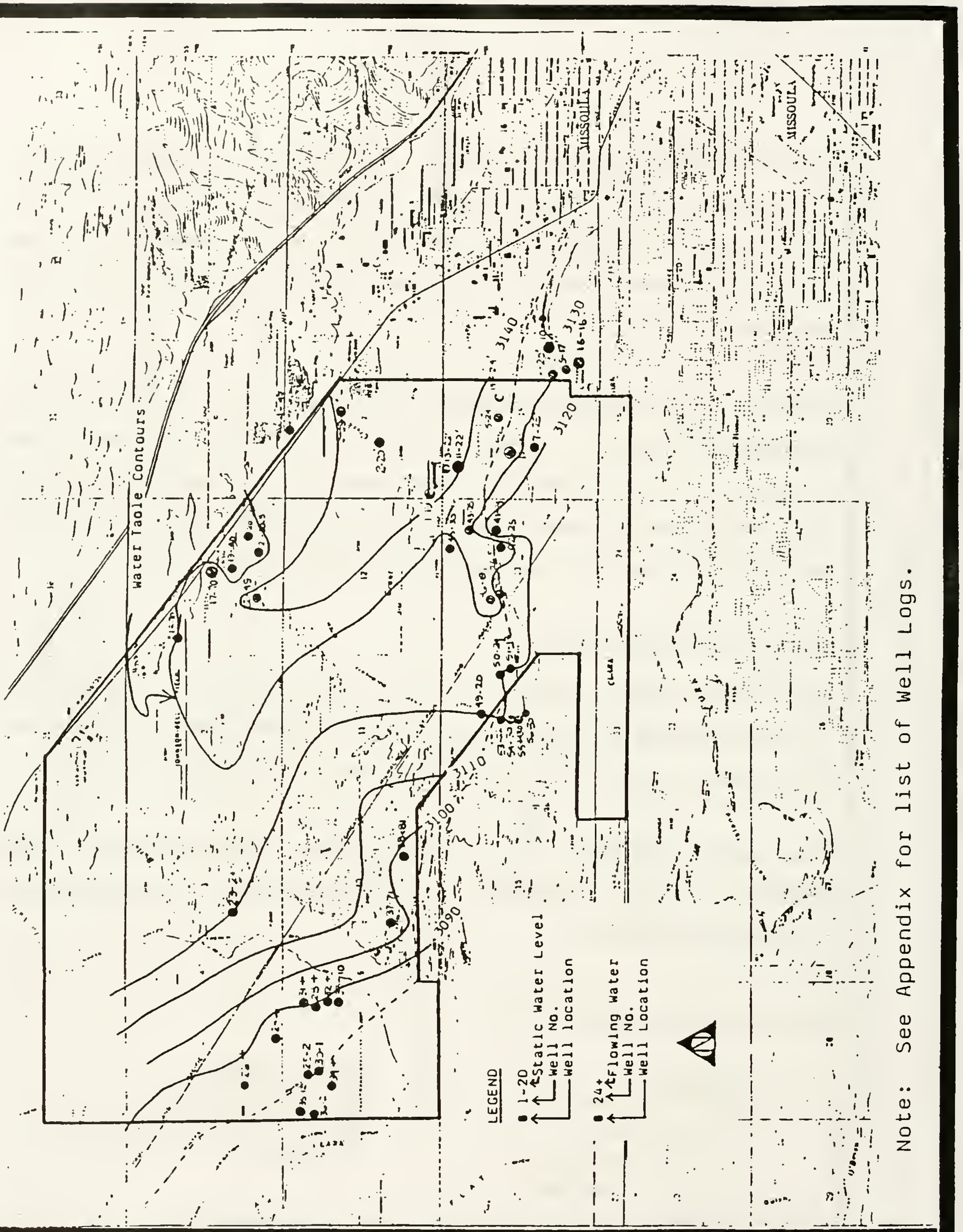
MODELING ASSUMPTIONS

The RI basin location analyzed is shown in Figure 5 based upon the selection process previously described. In essence, the location represents a first choice that minimizes impacts on the environment and people residing in the vicinity.

The hydraulic coefficients utilized in this preliminary analysis are based on published values representing studies completed in the area of or the general vicinity of the study area (Figure 3).

Table 4. Hydraulic Coefficients

Parameter	Estimated Value
Aquifer thickness (m)	120 ft. [Woessner 1988]
Transmissivity (T)	154,010 ft^2/day [Woessner 1988]
Hydraulic conductivity (K) $K = \frac{T}{m}$ [Todd 1980]	1,283 ft/day
Porosity	0.20 [Woessner 1988]



Note: See Appendix for list of Well Logs.

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FIGURE 9. Well Locations and Static Water Levels.

General boundary conditions were assumed based on available information. On the south side of the study area the model is bounded by the Clark Fork River. This was assumed to represent a constant head boundary with a slope equivalent to the river profile reported on USGS topographic quadrangles (10.4 ft/mile). The northwest model boundary is a constant head boundary defined by the contact of Tertiary sediments with Pleistocene valley fill [McMurtrey, Konizeski and Brietkrietz 1965]. Flow conditions on this boundary are defined by static water levels reported on well logs for well in the vicinity (Figure 9). From the end of the Tertiary/Pleistocene contact west to the northwest corner of the model, a constant head boundary is assumed with a slope defined by the regional water table gradient [Woessner 1988]. The eastern and western boundaries of the model are varying head boundaries that are initially defined by the regional water table gradient [Woessner 1988].

This preliminary analysis assumes a single layer, homogeneous aquifer. Prior to completion of a final design, a more appropriate 3 layer transient model should be used to adequately evaluate performance and impacts of proposed RI basins on this hydrogeologic system. As others have done [Woessner 1988], this model assumes no recharge to the groundwater system from Grant Creek. The datum elevation assumed for this model is 3100 ft MSL.

Other general assumptions include top and bottom of aquifer elevations. For example, at the Tertiary contact the estimated land surface elevation is 3220 ft MSL; top of aquifer, 3160 ft, and base of aquifer, 3040 ft. At the southwest corner of the model , the river surface elevation is 3092 ft; top of aquifer, 3077 ft, and base of aquifer, 2957 ft.

The estimate of conductance (ft^2/day) [McDonald and Harbaugh 1984] for the flux boundaries, east and western edges of the model, is 30,792. This value is based on K (model), cell dimensions (thickness and width), desired head value and realistic head gradients at the edge of the model.

FLOW MODELING

Based on the preceding information and assumptions, a preliminary flow analysis was preformed to estimate impacts of basin operation on existing groundwater systems. Basin configuration, shown in Figure 5, a loading rate of 9 mgd and an infiltration rate of 0.12 ft/day were incorporated into the MODFLOW model simulating flow in the vicinity of the basins. Water table elevations [Woessner 1988] were imposed on the groundwater system to simulate the "normal" background condition. No data is available that documents the location of the bottom of the aquifer [Woessner 1988]. For this model, the bottom of the aquifer was assumed to parallel the ground surface with a thickness of 120 ft. based upon prior studies [Woessner 1988]. Results of model calibration are shown in Figure 10 which also illustrates the water table surface in the vicinity of the proposed basins with no groundwater recharge due to basin loading. The grid lines represent sections with the basins located in section 12, T13N, R20W. The basins were located in the northwest corner of the section to minimize environmental impacts and conflicts with existing land uses. Actual location of the basins may vary in the final design. The calibrated model conforms reasonably well with the published data.

Basin loading and infiltration were modeled according to the values estimated by the previously described methods. Figure 11 illustrates the water table surface

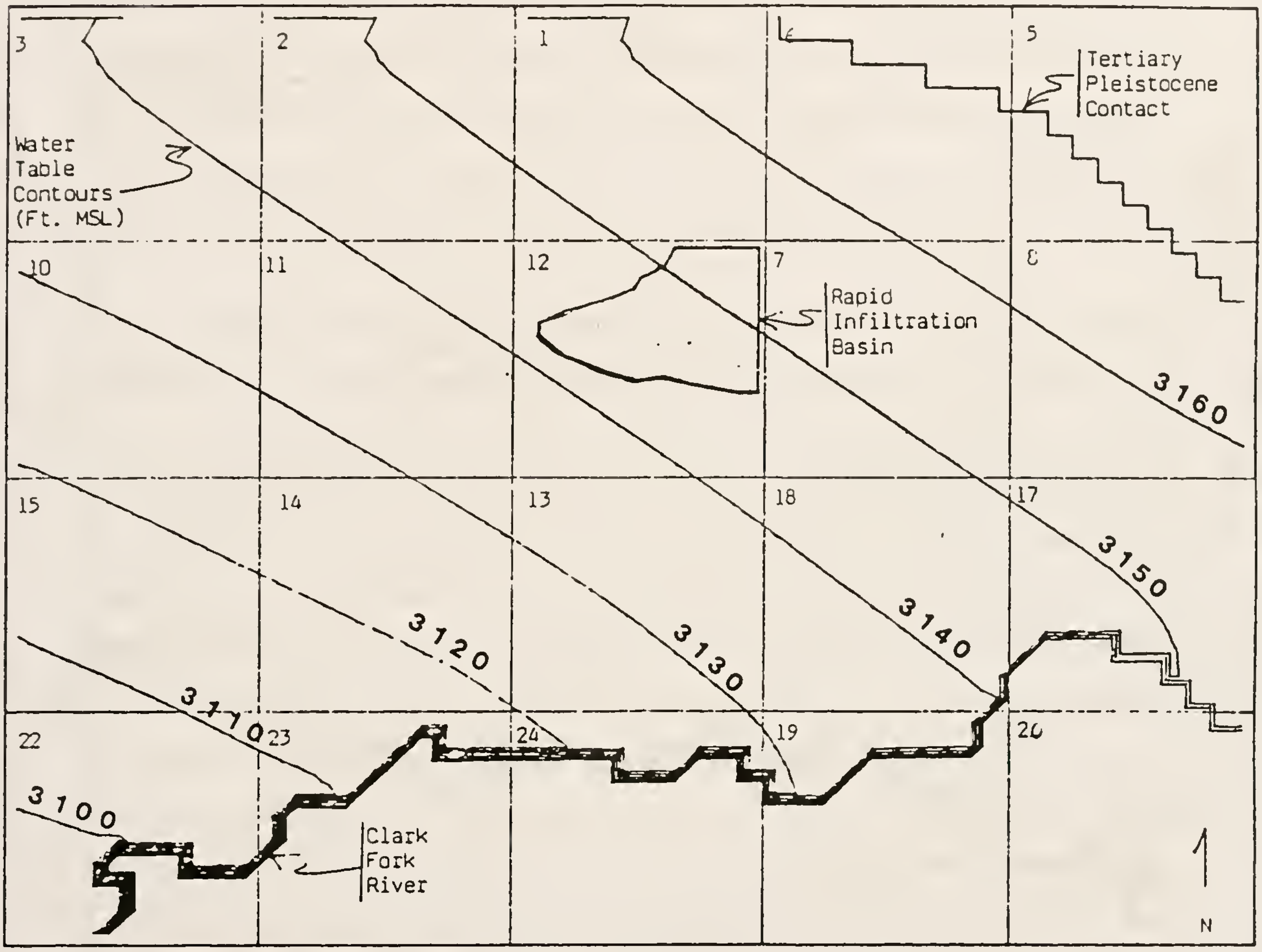

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FIGURE 10. Potentiometric Map - No Loading Surface.

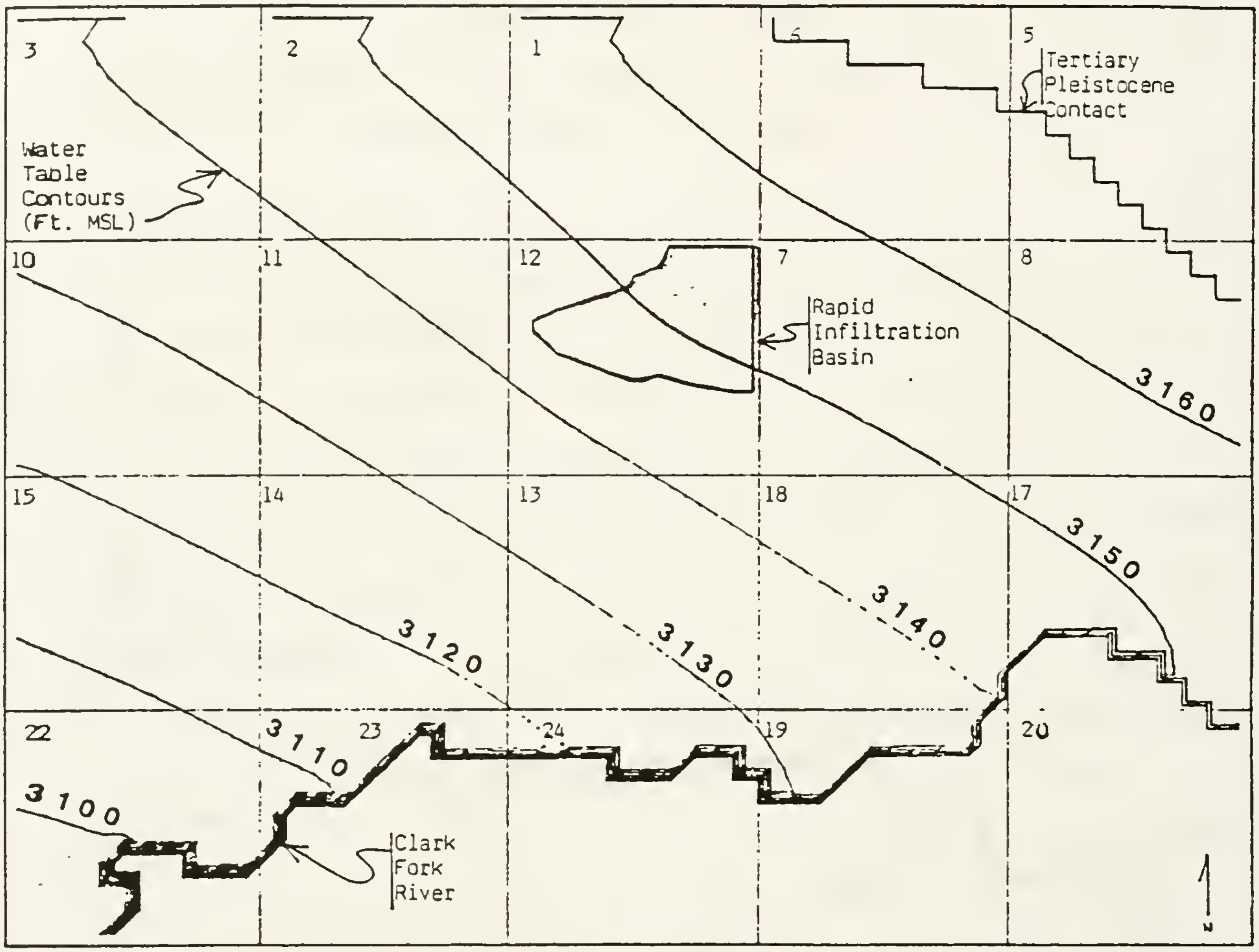

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FIGURE 11. Potentiometric Map -
Steady State Dosing at 9 mgd.

with the basins loaded at 9 million gallons per day (mgd) under steady state conditions. The effective average recharge rate over the R.I. basin area used in the model was 0.12 ft./day. Modeling discussed previously in this report demonstrated that the annual loading schedule proposed for these basins approximates a steady state condition. When overlayed on the base model, very little change is apparent in the water table configuration due to basin loading.

Even though little impact on the water table contours in the vicinity of the basins is evident on the potentiometric maps, mounding is occurring. To illustrate the mounding, the base contours were subtracted from the loaded basin contours. The differences are plotted as contours in Figure 12 illustrating net mounding due to basin loading. The maximum predicted mound height is 2.8 ft. above the normal water table elevation below the basin bottoms (Figure 13). Based on water table elevations measured during this study, the maximum water table elevation under the basin resulting from basin loading and mounding would be approximately 17.2 feet below the basin bottom. Measurable mounding (.5 ft) is predicted 4100 feet from the basin center. Less than .5 feet of mounding is predicted one mile from the basin center. The normal water table gradient in the vicinity of the proposed basin is 3.79 ft. per mile [Woessner 1988] which, coupled with the predicted mounding, indicates no hydraulic problems (such as water surfacing) are likely to occur due to basin loading.

GROUNDWATER WATER QUALITY

With a groundwater flow model configured, impacts on groundwater quality were estimated using a chemical transport code for dilution and dispersion effects. The transport code, proprietary to HydraLogic, was used in a two dimensional format based on concepts developed by the Illinois State Water Survey

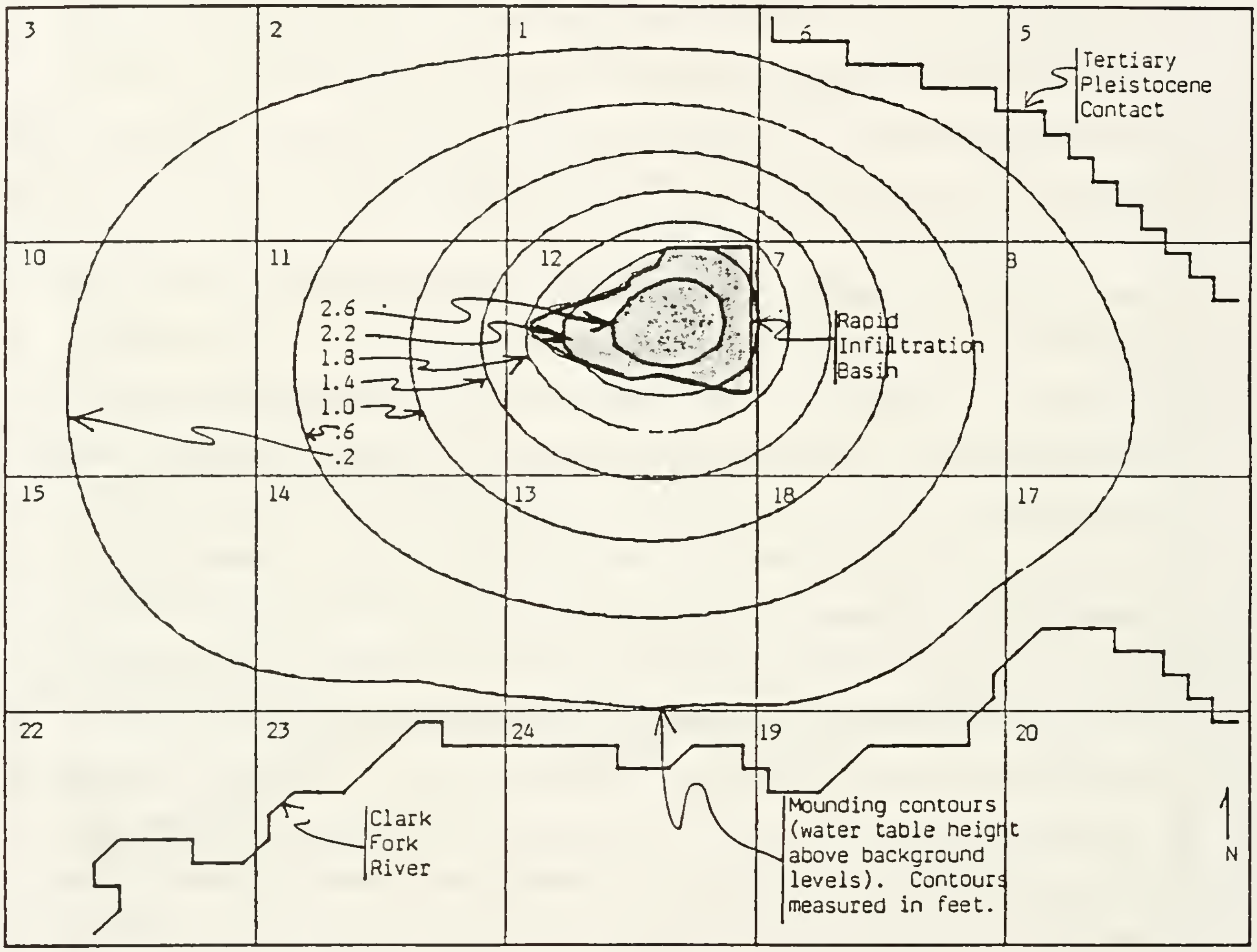

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FIGURE 12. Potentiometric Map- Net Mounding.

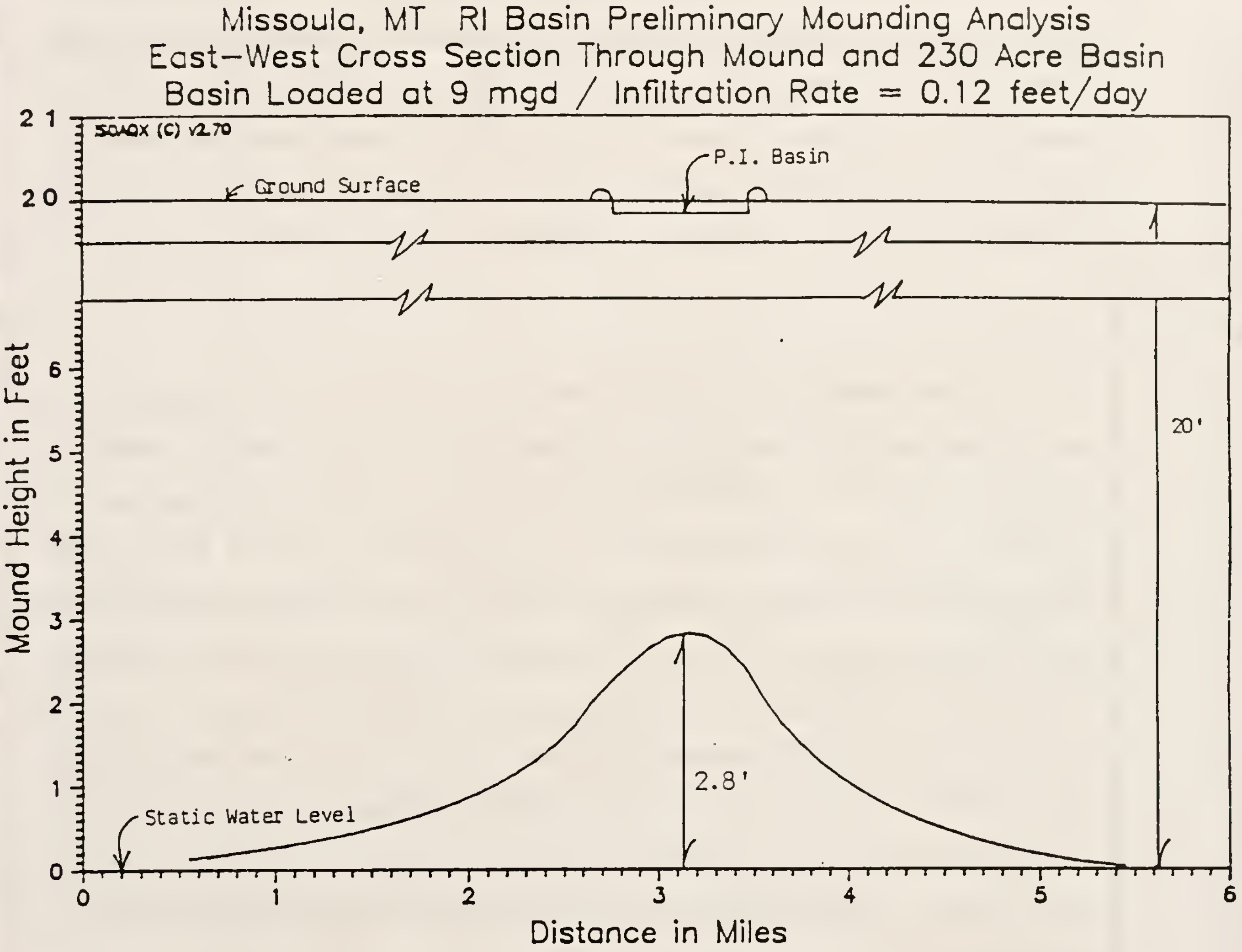
Missoula, MT RI Basin Preliminary Mounding Analysis
East–West Cross Section Through Mound and 230 Acre Basin
Basin Loaded at 9 mgd / Infiltration Rate = 0.12 feet/day

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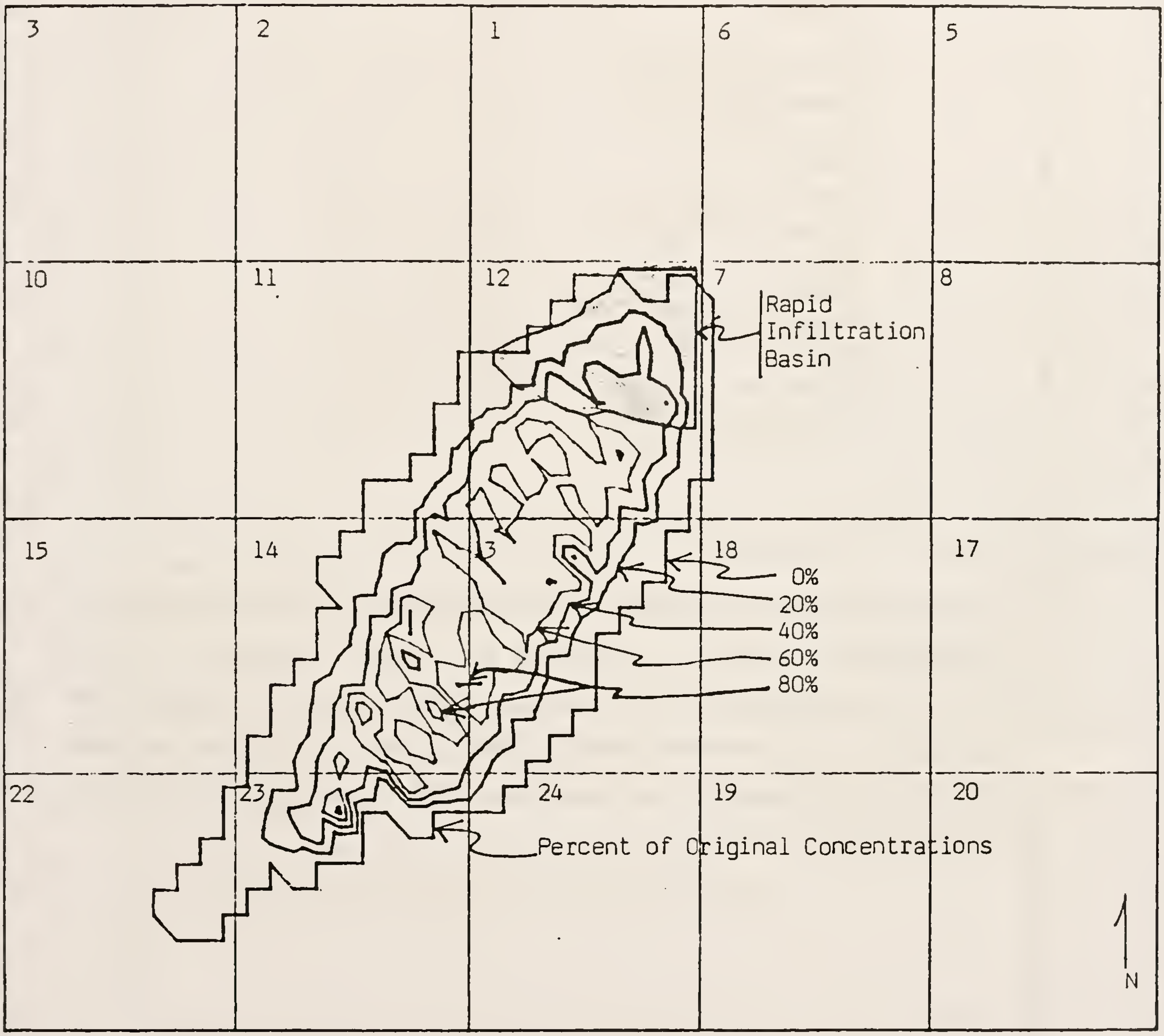
FIGURE 13. PREDICTED MOUND

[Prickett, Naymik, and Lonnquist 1981]. Impacts projected are for conservative ions (ions that tend to stay in solution). Predicted impacts are therefore greater than those actually experienced due to effluent renovation by other processes. Most cations, such as heavy metals, cadmium and lead, are readily removed from the water column by adsorption onto mineral surfaces. Phosphorus precipitates in the presence of dissolved calcium forming a non-reactive precipitate. It is also removed biologically by metabolic consumption of the phosphate forms in solution.

The shape and extent of the contaminant plume generated by the waste water injected into the groundwater system at the rapid infiltration basins is shown in Figure 14. The contours represent fractional concentrations after two years of operation. Injected concentrations fall to approximately 60% of their original value by the time the plume intercepts the Clark Fork river. Since no chemical reactions are assumed in this transport model and the model pictured is essentially at steady state, the conclusions that can be drawn are with respect to the areal limits of the plume, and although not shown here, the model indicates the plume reaches the river in a little over one year. From modeling as demonstrated here, no conclusions regarding nutrient loading of the river can be drawn without further modeling incorporating the reality of chemical and biological reactions within the aquifer.

Water quality information is provided in several sources. Groundwater concentrations for reported parameters in the vicinity of section 12 (section 13, T13N, R20W) are:



Note: Based on 2 year simulation.

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FIGURE 14. Contaminant Transport Modeling in Fractional Concentrations.

Table 5. Groundwater ambient water quality [Juday and Keller 1978].

Parameter	Concentration (mg/l)
Turbidity	0.28
pH	7.4
Bicarbonate (meas.)	271.8
Bicarbonate (calc.)	271.2
Sulfate	21.2
Chloride	8.4
Nitrate-Nitrogen	3.31
Phosphate-Phosphorus	0.019
Silica	15.4
Calcium	61.0
Magnesium	21.3
Sodium	11.3
Potassium	3.6
Total Dissolved Solids	428.6

Treated sewage effluent concentrations reported for the Missoula Wastewater Treatment Plant, which will be injected at the rapid infiltration basin site [Missoula 1989] indicate that the City is discharging a relatively high quality effluent with a low organic carbon content. Table 6 lists the reported average concentrations for the month of September, 1989, for treated sewage effluent from the Missoula STP.

Table 6. Missoula STP Wastewater average constituent concentrations, Sept. 1989.

Parameter	Constituent (mg/l)
pH	6.87 - 7.24
Total Solids	19.0
Ammonia - N	8.51
Total Nitrogen - N	34.4
Nitrite + Nitrate - N	8.71
Total Phosphorus - P	4.20
orthophosphate - P	3.09
Carbonaceous BOD	7.3
Flow (mgd)	5.79

Two constituents are of primary concern: phosphorus and nitrogen. At present, the City is discharging approximately six mgd of effluent with a total phosphorus concentration of 4.20 mg/l (210.3 lbs./day). Based upon a dilution factor of 60 %, the phosphorus load to the river will be reduced to 1.68 mg/l or 84 lbs./day. Based upon operating systems [Reed, Middlebrooks and Crites 1988], a total phosphorus concentration of less than 1 mg/l can be expected in the effluent reaching the river. As a general rule, phosphorus concentrations decline rapidly in groundwater systems such as the Missoula Valley Aquifer due to the relatively high concentrations of dissolved calcium in the groundwater.

Review of the potential concentrations suggests that a reduction in nitrogen concentrations of 50 -80% are reasonable based on studies of secondary effluent in Phoenix, Arizona [Reed, Middlebrooks and Crites 1988]. If the objective is to maximize total nitrogen removal, maximizing hydraulic loading is sacrificed to design for optimum denitrification.

Loading schedules directly affect ammonium adsorption during wetting, while drying schedules affect oxygen mass transfer and diffusion into soil. To achieve complete nitrification of the ammonium nitrogen, the amount of ammonium nitrogen applied during loading is balanced against the amount of oxygen entering the soil profile during drying.

Loading periods must be long enough to maximize ammonium adsorption and develop an anoxic environment to allow denitrification. The organic carbon source provided must be sufficient to support adequate denitrification. Using appropriate design methods [U.S.EPA 1984], total nitrogen removals are expected in excess of 60% and the discharge of total nitrogen is expected to be below 10 mg/l for typical municipal wastewaters during warm weather.

The infiltration rate can be fine-tuned to enhance denitrification by operating at reduced depth of ponding or by adding suspended solids. However, this will result in additional sacrifice of loading and will increase the land areas required. Selecting a site which naturally has low infiltration rates, or compacting the soil surface, can assure high total nitrogen removal rates but either increases the land area needed. Reducing the infiltration rate increases contact time between the soil micro-organisms and nitrate-nitrogen therefore more efficient denitrification can be accomplished. One of the most important factors for producing denitrification is to have near-saturated conditions in the soil media.

Optimum total nitrogen removal in land treatment systems can be achieved by adjusting the loading period to insure complete nitrification of the the ammonium nitrogen in the sewage and adjusting the infiltration rate to provide the needed level of denitrification. The use of primary effluent allows maximum total nitrogen removal at higher infiltration rates due to its higher organic carbon content. Nitrification reaction rates in the soil will be significantly reduced in the winter in cold climate areas. Winter storage is necessary for those RI systems designed for maximum nitrogen removal.

Nitrogen presents a more complex problem, the solution of which is beyond the scope of this study. However, based upon the predicted dilution factors of 60% at the river, the total nitrogen concentration would be 13.8 mg/l. Previous RI systems have maintained a 30% removal efficiency over the long-term [U.S. EPA 1981] and with proper basin construction and operation, efficiencies can be increased to 80%. Thus, total nitrogen (based upon an STP effluent concentration of 34.4 mg/l) reaching the groundwater system under the basin could be as low as 6.88 mg/l. Adding the dilution factor of 60 %, the concentration at the river becomes 2.75 mg/l. Note however, the steady, non-reacting transport model implies no reduction of total pollutant mass. This can be accomplished only through in-transit chemical and biological reactions which were not considered in this preliminary transport model.

The plume may impact several wells in section 13, T13N, R20W. The nearest downgradient well is approximately 3,000 ft from the basin. To evaluate the risk of contaminating the nearest well, dispersion was increased 10 fold. Under this scenario, the plume created by basin loading during a two year cycle did not significantly change. This preliminary modeling indicates that nitrogen concentrations in the groundwater may change. Concentrations in the effluent reaching the groundwater are higher than the ambient groundwater levels (6.88 mg/l vs.

3.31 mg/l). These values are presented as a simple comparison. They are not directly comparable as the first is total nitrogen and the second, nitrate + nitrite. In a system such as this, the majority of the total nitrogen is converted to nitrate prior to introduction to the groundwater system by oxidation and metabolic processes occurring in the soils. Modeling transient conditions and cumulative impacts are beyond the scope of this report.

REPORT LIMITS

The results of this investigation represent conditions at the time and location samples were collected and tests performed in the field. This investigation is limited by its scope and does not fully characterize the site nor predict contamination under conditions other than those documented in this report.

SUMMARY

An area suitable for RI basins was located in Section 12, T13N, R20N of 230 acres. The available soils have permeabilities at the low end of the desired rates but appear suitable. Three areas were located within the study area that could potentially satisfy minimum requirements of 230 contiguous acres and a permeability of 0.6 in/hr or greater. The system could be operated year-round and result in significant reductions in phosphorus additions to the Clark Fork River. Indeed, an estimated 38 tons per year of phosphorus presently added to the river could be reduced to nine tons per year. Nitrogen addition to the river could also be greatly reduced however, a plume of elevated nitrogen concentrations will extend from the basin area to the river. As a result, it appears that degradation of a measurable amount will occur in the affected portion of the Missoula Valley aquifer. To construct this treatment system a variance to the non-degradation rule of the MDHES will have to be obtained.

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APPENDICES

Well logs

MISSOULA WELL LOGS

NO.	OWNER	S	T (N)	R (W)	QUARTERS	CASING SIZE (IN)	DEPTH (FT)	DIS-CHARGE (GPM)	TIME DIS-CHARGE (HRS)	PUMPING WATER LEVEL (FT)	STATIC WATER LEVEL (FT)	COMPLE-TION DATE
1	SCHOOL DIST 4	7	13	19	SWSWSW	6 5/8	71	150	8	30	19	7/15/75
2	JIM & SUSAN GUEST	7	13	19	NWSW	6 5/8	60	30	1.5	29	20	8/13/84
3	BAKKE TIRE COMPANY	7	13	19	SWNE	6 5/8	78.5	60	1	50	39	8/5/85
4	WASHINGTON CORP	7	13	19	NW	6 5/8	122	25	2.5	53	47	4/22/88
5	BOB E. EDWARDS	18	13	19	SWNE	6 5/8	65	90	2	27	24	7/16/73
6	PEW CONSTRUCTION	18	13	19	SENE	6 5/8	98.5	75	1	80		3/9/77
7	OSCAR KOEPPLIN	18	13	19		6 5/8	50	30	1.5	37	25	10/5/84
8	RICHARD MORGENSTERN	18	13	19	SENESE	6 5/8	57	100	1	25	20	6/26/77
9	KEN & HELEN McCULLOCH	18	13	19	SENESE	6 5/8	57.5	75	1	40	17	11/28/75
10	L.M. NEILSON	18	13	19	SE	6 5/8	41	60	2	37	9	6/29/78
11	BRUCE T. SIREN	18	13	19	NWNW	6 5/8	59	75	1	50	22	6/7/79
12	HARVEY R. CLOUSE	18	13	19	SENW	6 5/8	51	100	1	18	13	3/20/73
13	JACK FLYNN	18	13	19	NENWNW	6 5/8	52.5	25	1.5	25	22	6/23/77
14	DARRELL BECKWITH	18	13	19		6 5/8	59	75	1	59	20	8/16/83
15	PATRICK MANGAN	18	13	19	SWNE	6 5/8	57	75	1.5	55	24	6/24/77
16	CITY OF MISSOULA	18	13	19	SESE	6 5/8	118.5	95	1.5	90	16	10/14/77
17	NEIL R. MILLER	1	13	20	NWSE	6 5/8	239	75	3	101	70	6/9/63
18	NEIL R. MILLER CO	1	33	20	SWNW	6 5/8	139	75	3	101	70	6/5/68
19	BOB McCUE	1	13	20	NESE	6 5/8	70	20	1	50	40	4/8/77
20	M.E. JOHNSON	1	13	20	SE	6 5/8	70	30	1.5	36	25	11/2/83
21	M.E. JOHNSON	1	13	20	SWSE	8 5/8	72	40	3	32	30.5	12/28/76
22	JIM BAUER LOGGING	1	13	20	SESW	6 5/8	90	20	1	60	49	3/17/77
23	CHARLES DESCHAMPS	3	13	20	NWSW	6 5/8	119	35-40	6	2	2+	1/10/75
24	ARCHIE GORDON	4	13	20	SWSWSE	6 5/8	99	100	1	40	(3-5PSI 50GPM)	9-14-87
25	NICK KAUFMAN	4	13	20		6 5/8	99	125	3.5	125	(4PSI 60GPM)	6-6-88
26	T & T CONSTRUCTION	4	13	20	SE	6 5/8	118.5				(4PSI 200GPM)	6-6-88
27	DAVID COLEY	4	13	20	SWSW	6 5/8	95				12	12/31/63
28		9	13	20	NE	8 5/8	139				(3.5PSI 620GPM	6-4-80

MISSOULA WELL LOGS

NO.	OWNER	S	T (N)	R (W)	QUARTERS	CASING SIZE (IN)	DEPTH (FT)	DIS-CHARGE (GPM)	TIME DIS-CHARGE (HRS)	PUMPING WATER LEVEL (FT)	STATIC WATER LEVEL (FT)	COMPLE-TION DATE
29	KARL TYLER	9	13	20	NW	6 5/8	109.5	100	1	109	2	6/26/80
30	EMMA JETTE	9	13	20	SWNENW	6 5/8	110	60	6	2	1	12/15/77
31	EDWARD WORDEN	9	13	20	NENE	6 5/8	100	20	1	20	(4PSI 20GPM	8-20-79
32	RUSSEL KAMURA	9	13	20	NWSENE	8 5/87	97.5	200	1.5	2	(3PSI 80GPM)	6-29-78
33	GUE	9	13	20	NE	6 5/8	40	30	2	25	10	2/20/79
34	DAVE HINTZMAN	9	13	20	NW	6 5/8	98	150	1	95	(IPSI 5PGM)	3-22-79
35	GEORGE DUSSAULT	9	13	20	NWNW	6 5/8	105				12	12/31/63
36	JOHN STEIGLER	9	13	20	SWNWNW	6 5/8	109.5	100	1	109	2	6/26/80
37	EL MAR ESTATES	10	13	20	SW	8 5/8	212.5	650	8		71	6/24/75
38	EL MAR ESTATES	10	13	20	SE	8 5/8	222	650	8	85	81	6/24/75
39	GUSTAV & ARLENE BRUNS	11	13	20		8 5/8	121	50	1	75	50	5/28/86
40	PRUYN & SWARTZ	11	13	20	NW	6 5/8	98	40	2	37	25	11/2/83
	PRUYN & SWARTZ IN SECTION 12 IN WRB REPORT											
41	VINTON & LINDA GUTHRIE	13	13	20	NE	6 5/8	54.5	60	2	32	24	12/13/79
42	DWAYNE GARBER	13	13	20	NE	6 5/8	60	30	1	37	25	11/25/85
43	C. & B. SKAGGS	13	13	20	SWNENE	6 5/8	50	50	2	30	25	9/12/84
44	GARY CORDIS	13	13	20		6 5/8	50	50	1	45	24	11/8/84
45	A. & A. TALLY	13	13	20	NENWNE	6 5/8	90	25	2	65	30	9/21/83
46	ERNEST ASHENBRENNER	13	13	20	SENW	6 5/8	68.5	100	2.5	68	19	9/3/82
47	FLORENCE WOOD	13	13	20	SENW	6 5/8	77.5	80	2	40	26.5	2/2/74
48	JEAN JANECEK	13	13	20	NESW	LOG UNREADABLE						
49	J. & L. HELMER	14	13	20	NE	6 5/8	90	18	1	75	20	9/15/77
50	ROYAL McCONKEY	14	13	20	SENE	6 5/8	88	75	1.5	31	24	6/1/73
51	ROYAL McCONKEY	14	13	20	SENE	6 5/8	85	75	2	21	17	5/29/73
52	J.B. YONCE	14	13	20		6 5/8	90	75	2	25	21	5/14/79
53	JIM HELMER	14	13	20	NWSWNE	6 5/8	93	100	2	26	22	6/4/79
54	RUTH'S REALTY	14	13	20	SWSWNE	6 5/8	90	45	1	40	30	4/27/78

MISSOULA WELL LOGS

NO.	OWNER	S	T (N)	R (W)	QUARTERS	CASING SIZE (IN)	DEPTH (FT)	DISCHARGE (GPM)	TIME DISCHARGE (HRS)	PUMPING WATER LEVEL (FT)	STATIC WATER LEVEL (FT)	COMPLETION DATE
55	RUTH'S REALTY	14	13	20	SWSWNE	6 5/8	90	40	1	40	30	4/28/78
56	RUTH'S REALTY	14	13	20	SWSWNE	6 5/8	90	45	1	40	30	4/26/78
57	RUTH'S REALTY	14	13	20	SWSWNE	6 5/8	90	50	1	40	30	4/25/78
58	SHEILA LINDQUIST	14	13	20		6 5/8	93	25	2	80	35	3/11/88
59	KELLY BRAUDT	14	13	20		6 5/8	100	80	2.5	40	30	3/10/88

S 1/2 OF SECTIONS 33, 34, 35 T14N R20W UNAVAILABLE AT WRB